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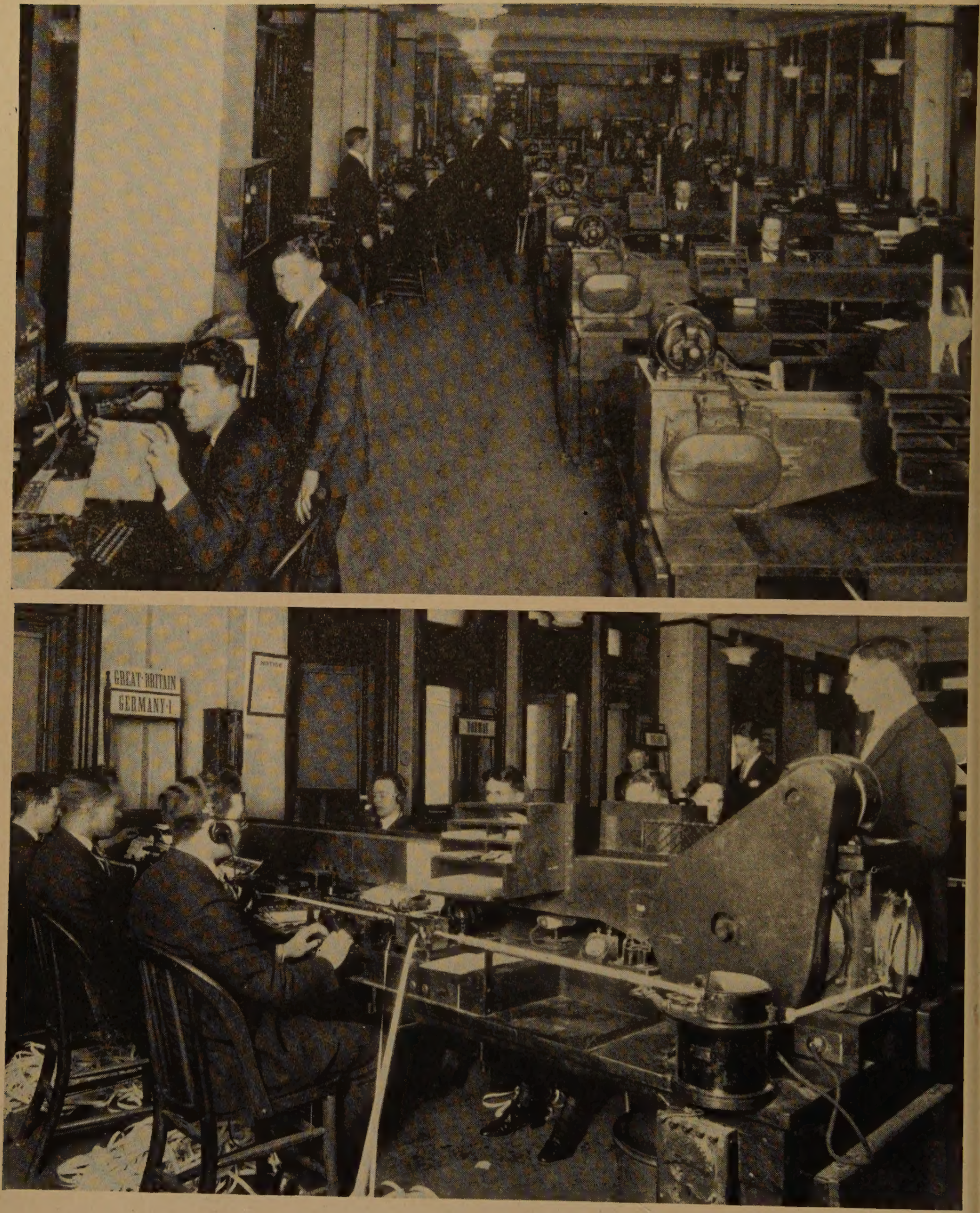

THE VOICE AND EAR OF A WORLD WIDE WIRELESS SYSTEM

Operating Room of the Radio Corporation of America, New York City. Outgoing messages are radiated from independent transmitters, according to destination. Incoming messages are electrically separated and recorded after reception on a single antenna. (See page 373)

GENERAL ELECTRIC REVIEW

HUDSON AVE. STATION OF THE BROOKLYN EDISON CO.

The Hudson Avenue Station of the Brooklyn Edison Company was placed in operation May 12, 1924. This station with an ultimate capacity in eight units of 400,000 to 500,000 kw. gives to Brooklyn and the Metropolitan district, through interconnections, an additional source of power supply from the world's largest proposed station now in operation.

The developments in apparatus for the generation and distribution of electrical energy have been very rapid as the result of close coöperation between public utility companies and manufacturers. These developments have been accelerated by the great demand for large amounts of power, which will be efficiently produced, provided with every safeguard for continuity of service and safety in operation, and which will enable the engineers of the operating company to provide a maximum reliability of service to the ultimate consumer.

The Brooklyn Edison Company furnishes electric service to a population of two million in an area of eighty-one square miles. Hudson Avenue, located on the East River, between the existing Gold Street plant and the Navy Yard, is admirably situated with respect to the existing system.

In the building of this station full advantage was taken of the recent advancements in station and apparatus designs, and in addition it incorporates many new and novel features that are outstanding, and mark a mile-stone in generating station development.

One of the features of the station is the world's largest turbine generator unit operating at 1200 r.p.m.

The unit furnished by the General Electric Company is a single-cylinder turbine driving a single generator. The turbine is designed for operation at 265 lb. gauge pressure at the throttle, 200 deg. F. superheat, and 1 inch absolute back pressure. Provision is made for extracting steam from two stages, all of which is used for feed-water heating. The generator is rated 50,000 kw., 80 per cent p-f., 13,800 volts Y-connected. The closed air circulating system with water coolers is used, thus eliminating air washers and yet providing clean, dry air. This system also provides a maximum protection against the destructive effects from generator fires.

To follow through in order, the single-conductor leads from the generator go directly to single-phase auto-transformers which increase the generator voltage to 27,600, and which are located in separate compartments on the first floor of the switch house, and at one side, with openings to the yard. The auto-transformers are provided with cable pot-heads as an integral part whereby connections are made from petrolatum filled pot-heads to oil filled transformer cases without the emergence of copper conductors outside the grounded cable sheath, pot-heads, or transformer tanks. Phase separation and phase insulation, therefore, start at the generator terminals and continue throughout the switch house until each outgoing feeder passes beyond a current limiting reactor in each phase and to the pot-head of the three-conductor cable.

Each generator, with its corresponding auto-transformers, is protected as a unit by an over-all differential relay system in combination with a split-conductor system. This gives complete protection against internal failures, including generator, auto-transformer, and leads.

Isolated phase construction of either the horizontal or vertical arrangement had become very popular for large stations with indoor switch gear. Although little operating experience was available at the time, the basic principle seemed so sound that the vertical arrangement was selected. The principle was carried out in great detail, involving many new features in apparatus arrangement and operation.

Insulated single-conductor cable in ducts instead of the usual bus construction on insulators is used for all runs of bus not directly supported by the circuit breakers. The current transformers are mounted inside the switch, the potential transformers are oil filled, the selector switches for grounding and testing circuits are oil insulated and remotely controlled. The maximum of personal safety is therefore assured by the use wherever possible of metal clad gear.

The unusual part of the switch design is in the operating mechanism, each breaker unit being mounted in a cradle which is geared to two vertical jack screws on opposite sides of the switch tank. The jack screws on each floor are connected to universal joints, and are driven through a suitable mechanism by a 2½-h. p. motor.

For removing the switch from the structure, the tank is lowered on a truck and the cradle holding the tank is unfastened, allowing easy removal of the unit and the immediate substitution of another. Safety considerations have been carried out in every detail, and provide that the breaker cannot be closed unless it is in the clamped position.

Steel construction instead of slate is used for the entire switchboard control equipment. The steel housings for both vertical and bench sections extend through the floor to make accessible the connections to the control cables.

Ample provision is made for high-potential testing purposes; and a test room in which is located a 200,000-volt kenotron testing equipment, also the control for the ground and test switches, provides a safe and ready means of testing. For testing the generator windings a 500-kv-a. single-phase testing transformer with connections for 40 and 80 kv. to ground is provided.

The auxiliaries are supplied with power from the main bus sections through house transformers, and can obtain power from a house turbine set or from a frequency-changer set that operates from the 25-cycle Gold Street Station.

Twenty-seven thousand six hundred (27,600) volts was selected as the most economical transmission voltage as the station location with only two streets available for duct lines did not permit distributing the total station output at 13,200 volts.

T. F. BARTON

The Protection of Steam Turbine Disk Wheels From Axial Vibration*

By WILFRED CAMPBELL

TURBINE ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

Prepared with the co-operation of A. L. Kimball, Jr., Research Laboratory, and E. L. Robinson, Turbine Engineering Department; both of General Electric Company

PART I

One of the most important features in the design and manufacture of a steam turbine is the elimination of the possibility of vibration occurring at the various natural frequencies of its disk wheels and buckets. To accomplish this purpose the General Electric Company has for several years made an extensive investigation of various forms of vibration and waves which may exist in steam turbine disk wheels. One of the results was the determination of the laws of dangerous critical speeds that must be guarded against, together with other minor resonant conditions that it is advisable to avoid. Testing machines with complete auxiliary apparatus were developed for the verification of predicted frequencies and critical speeds, and a program for the routine testing of turbine wheels was instituted. This resulted in the determination and adoption of the procedure, necessary in all cases, for the definite protection of steam turbine bucket wheels from axial vibration, as justified by several years of successful manufacture.—AUTHOR.

A complete and detailed description of all this work will be printed in the REVIEW in serial form. The first part, which appears below, outlines the troubles which gave rise to the investigation and reviews the various preliminary channels along which study was conducted. A discussion of the real solution of these troubles and its reduction to commercial practice will appear in the July and August issues of the REVIEW.—EDITOR.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this article is to present the main features of the work done by the General Electric Company which led to the solution of the problem of vibration of turbine disk wheels, and to describe the way wheels are designed and tested in order to insure freedom from vibration.

The investigation was undertaken in order to account for wheel failures of a peculiar and erratic nature which could not be explained on the basis of high stress alone. The number of failures was small considering the total number of wheels in operation. These failures were not confined to any single type of machine, but they did show a preference in general for thin wheels of large diameter.

That this difficulty has actually been overcome with no major alteration in the turbine is emphatically brought out by results obtained by the General Electric Company in the past three years from its use of disk wheels properly designed and tested.

Up to the end of 1923, this company had manufactured and installed over 9000 steam turbines aggregating in total generating capacity more than 15,000,000 kw. This investigation is chiefly concerned with large size machines, that is, of over 5000 kw. capacity. Before the year 1919, the General Electric Company had manufactured and installed in operating plants a total of 227 turbines of ratings exceeding 5000 kw. each. The total generating capacity represented by these machines was over 2,404,000 kw. Since the year 1919, when this particular investigation was started, there have been 206 more turbines installed exceeding 5000 kw. each, increasing the total of generating capacity of the larger size turbines to 5,864,500 kw. at the end of 1923.

TABLE I

FOR TURBINES OF OVER 5000 KW. INSTALLED BEFORE MARCH 1, 1924

Number of wheels installed	4399
Number of wheels tested (standing)	3596
Number of wheels rotated in wheel testing machine	320
Number of tests in wheel testing machine	405
Number of wheels tested in customer's plants (standing)	1683
Number of machines investigated in customer's plants	291
Number of machines tested under load in customer's plants	24
Number of wheels replaced to avoid possible trouble	497
Number of wheels tuned for vibration	212

Table I shows the magnitude of the investigation, giving a few figures as to the number of machines and the number of turbine wheels investigated. The capacity of the testing machines now in operation is sufficient to provide for the testing of 600 wheels annually, under all conditions of speed.

That the methods developed are effective is attested by the successful elimination of all serious wheel and bucket troubles due to axial vibration from the operation of recently built turbines.

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*This article was presented as a paper at the Spring meeting of the American Society of Mechanical Engineers, May 26-29, 1924, at Cleveland, Ohio.

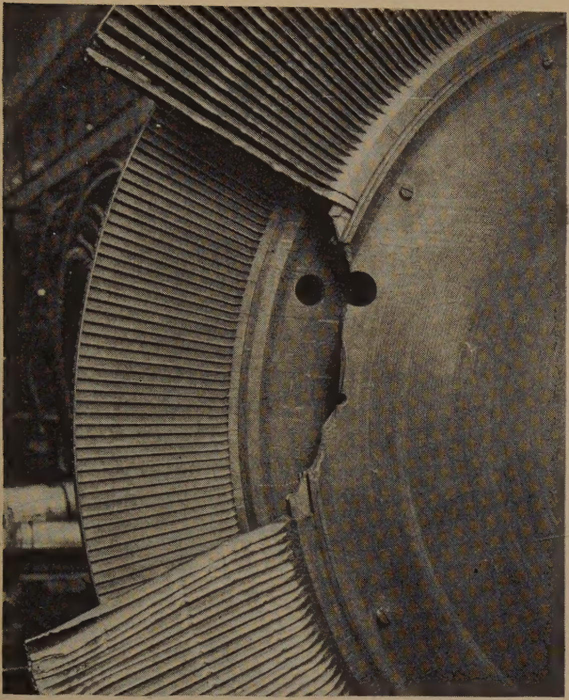


Fig. 1. Broken Turbine Bucket Wheel 9th Stage of 15,000-kw., 1800-r.p.m., 9-stage Turbine. This was caused by axial vibration of a type which has been eliminated by the investigation described in later parts of this article

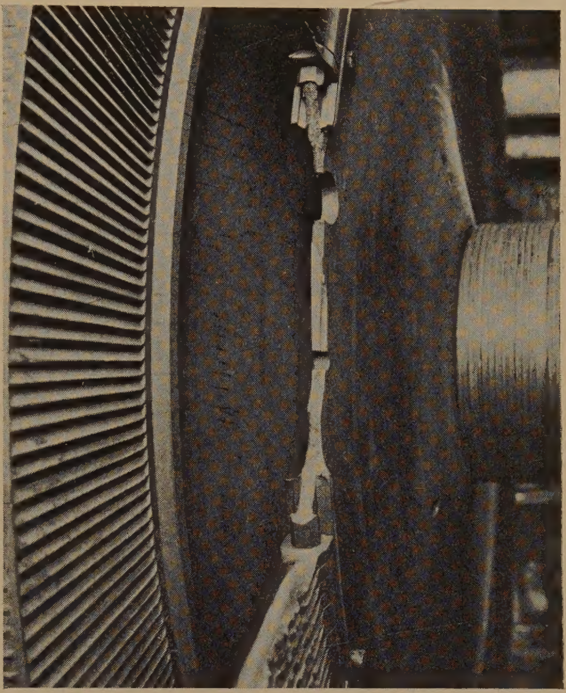


Fig. 2. Detail of the Fracture in Fig. 1, Showing Characteristic Fatigue Failure

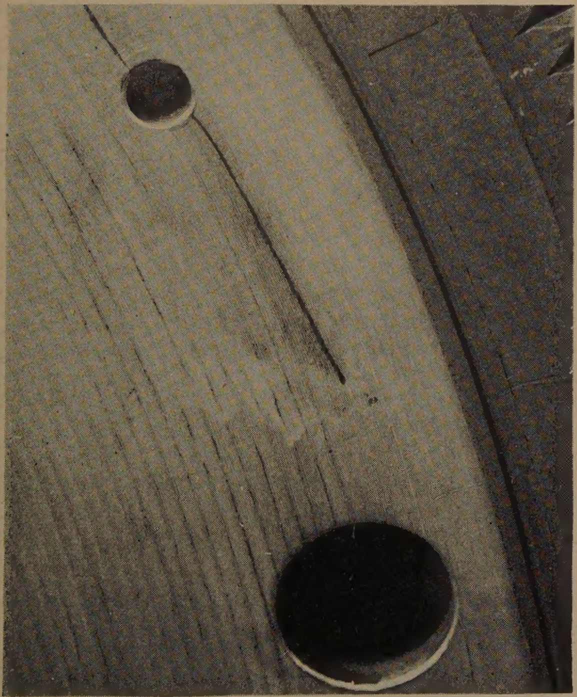


Fig. 3. Fatigue Crack which Started at a Hole

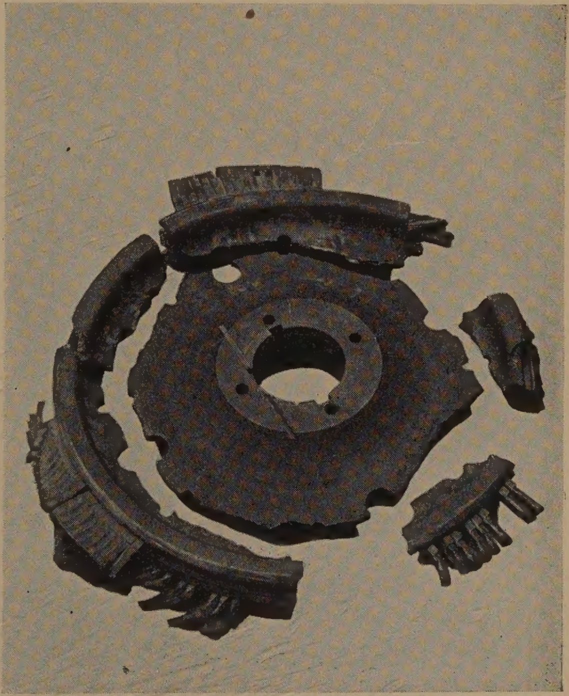


Fig. 4. Small Turbine Wheel Broken by Accidental Over-speeding, 2nd Stage of 500-kw., 3600-r.p.m., 3-stage Turbine

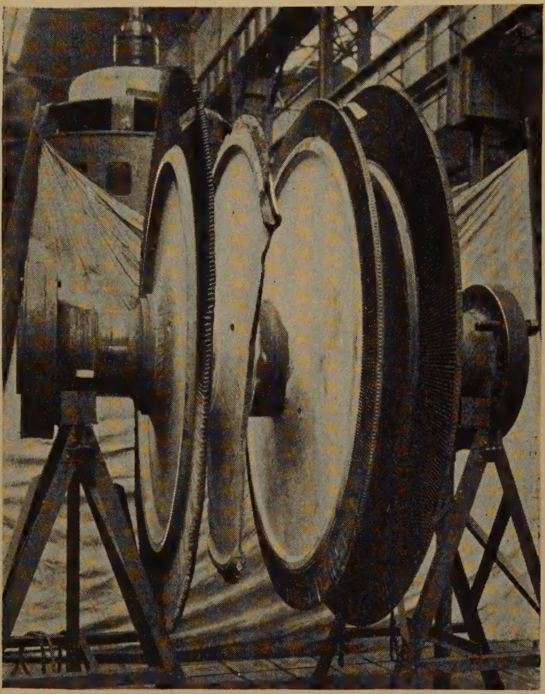


Fig. 5. Fatigue Failure which Did Not Pass Through Holes; 11th Stage of 30,000-kw., 1500-r.p.m., 12-stage Turbine

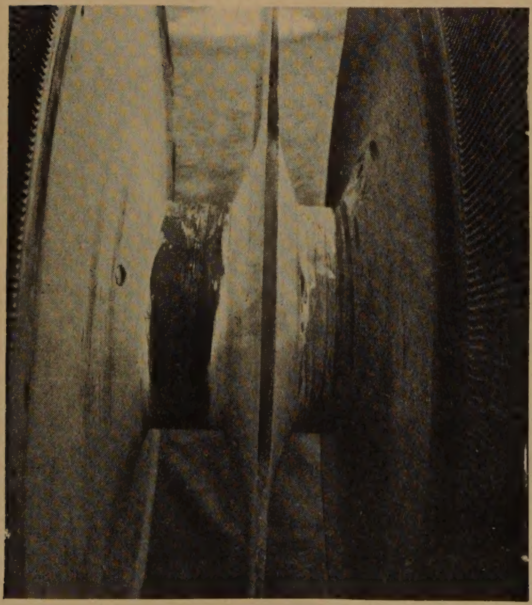


Fig. 6. Detail of Fig. 5, Showing Characteristic Fatigue Failure

HISTORICAL OUTLINE

Before discussing in detail the nature of the vibrations to which disk wheels are subject, a brief narrative of the work of investigation will be presented. This seems necessary in order to give a proper perspective of the problem as a whole.

Growth of Capacity

The design of turbines with one row of buckets per wheel took place long prior to the entry of America into the war. These designs used higher linear bucket velocities and were produced in unprecedented quantities during the war period. The rapid increases of turbine capacity which took place at the same time were in a large degree accomplished by the use of larger diameters introduced to give greater bucket speeds, and by using longer buckets. The mechanical possibilities were pushed to the limit. While some improvements in steam conditions came at the same time, the important thing to note is that the real period of increased capacity due to improved thermal processes occurred later and is still going on whereas, almost at one leap, the early designs were pushed to the limit from the point of view of structural strength.

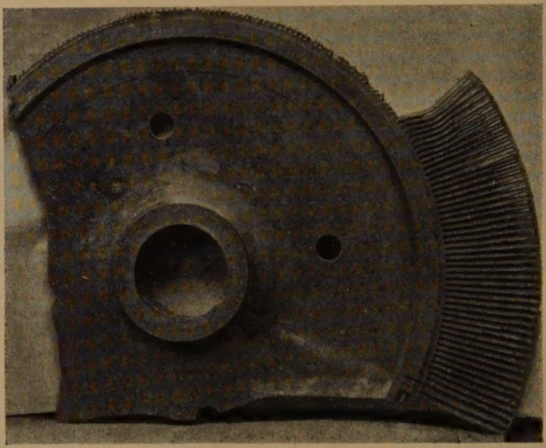


Fig. 7. Turbine Wheel Failure as a Result of Fatigue Bending; 3rd Stage of 6000-h.p. Turbine

Several principles of design pointed in the direction of light wheels. The maximum wheel stress is at the bore and this could be reduced by using lighter and thinner disks having less centrifugal bursting tendency. In fact, these were cut down in thickness as much as could be without creating a new maximum in the web due to the pull of the buckets. And not only did the desire for conservative stresses point toward light wheels, but also the desire for a stiff rotor. Heavy wheels are accompanied by lower critical shaft speeds. The unquestioned advantage of a stiff shaft, when possible, also dictated light wheels. These various influences were perfectly natural at the time. The subject of vibration had not been brought to prominence. It was hazy and uncertain and no difficulties had been experienced on this account. The plain path of reason seemed to be along the lines indicated.

Figs. 5 and 6 show a typical fatigue fracture which did not originate at a hole.

Fig. 7 shows a break in which cracks originated at more than one hole. Figs. 8 and 9 show details of this fracture at each of the two holes. Although Fig. 7 bears a resemblance in its completeness of failure to Fig. 4, the type of fracture is entirely different and characteristic of a fatigue failure.

In other cases the only damage was loss of buckets. Fig. 10 shows a wheel from which a number of buckets have been broken. In this case the breaks were due to axial vibration.

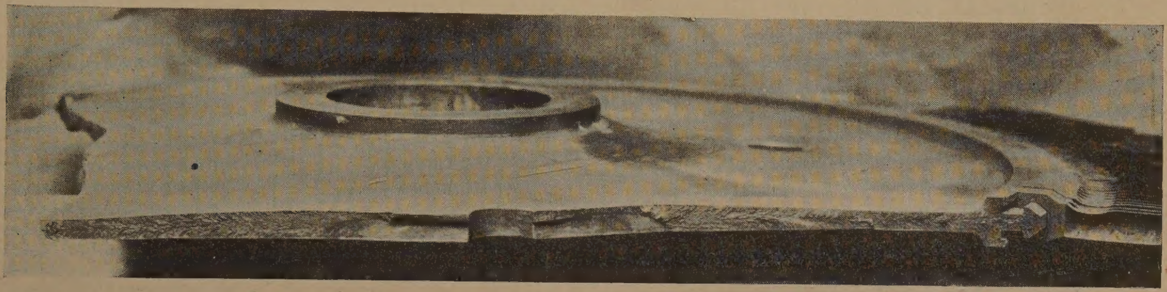


Fig. 8. Detail of Fig. 7, Showing How the Crack Started at One Hole

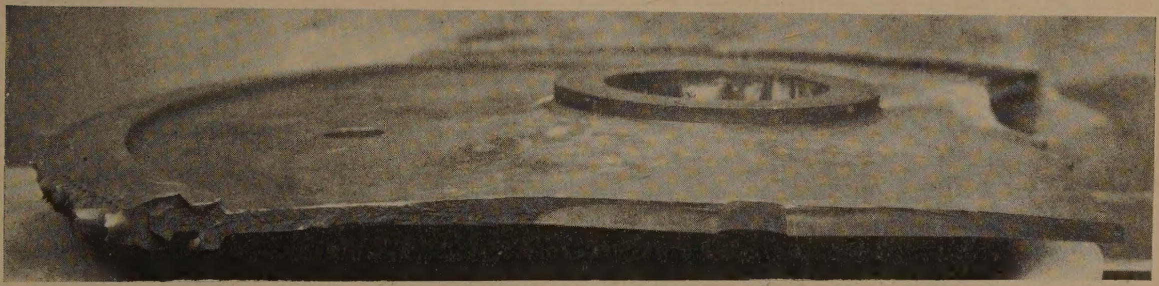


Fig. 9. Detail of Fig. 7, Showing How the Crack Started at Another Hole

Types of Failure

In order to visualize the sort of difficulty which led to the present investigation, it will be well to examine a number of failures.

Figs. 1 and 2 show a break which originated in a small tapped hole and passed through a large steam balance hole. This was a vibration fatigue failure. An examination of the fractured surface shows the characteristic central line and progressive curves. Fig. 3 shows another crack discovered before complete rupture in the same wheel.

Fig. 4 shows a wheel which completely burst. Note that the line of fracture has passed through every one of the holes in the web of the wheel. This was due to accidental overspeed.

In Fig. 11 various failures occurring in the bucket dovetail are shown. In each case the marking indicates vibration in an axial direction.

Fig. 12 shows another class of turbine trouble in which a diaphragm has been scored in two diametrically opposite spots by a rubbing wheel. Fig. 13 is a section of the same diaphragm at the point of greatest rubbing together with a profile of the wheel showing the shape taken by all of the buckets.

These examples will serve to illustrate the various types of failure. Most of them were plainly due to vibration resulting in fatigue. A few were clearly the result of accidental overspeed such as Fig. 4. In certain cases the fractures avoided holes, but in general there was a distinct affinity for holes owing undoubtedly to the higher localized stresses around them.

Hole Stresses

The first remedial measure used was to give immediate attention to the localized stresses in the neighborhoods of the steam balance holes and other discontinuities in the webs of the wheels.

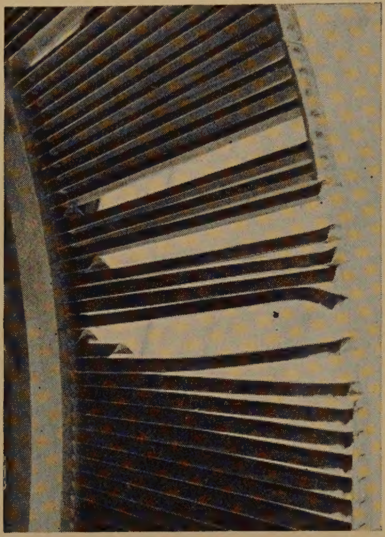


Fig. 10. Roots of Buckets Broken by Fatigue Bending Due to Vibration; 12th Stage of 10,000-kw., 1500-r.p.m., 12-stage Turbine

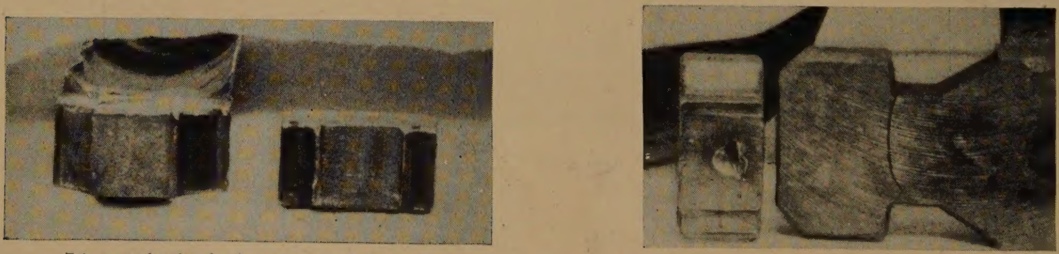
It is not the object of this article to discuss hole stresses, but it is necessary to note that they become serious only in connection with vibration, by constituting a place for a fatigue crack to start. If a wheel is properly protected from vibration, there will be no repeated stresses at any point. Rather elaborate experiments have shown that the reinforcement of holes will serve to increase the resistance of a wheel to vibration in case it should be necessary to design with the expectation of fatigue stresses. But the greater safety lies in guarding against the stresses themselves by the precautionary measures developed for use in manufacture.

Bucket Lacing

The early experiments on the vibration of buckets indicated that a lacing wire paralleling the shroud band and connecting different groups of buckets would remove various secondary vibrations. Although the fundamental period was not much influenced this expedient was actually used in a number of turbines. The lacing wire, however, failed to remove the cause of the trouble and became itself another hazard. During these experiments a taut wire attached to the end of each bucket raised the frequency thus illustrating the similar effect due to centrifugal force.

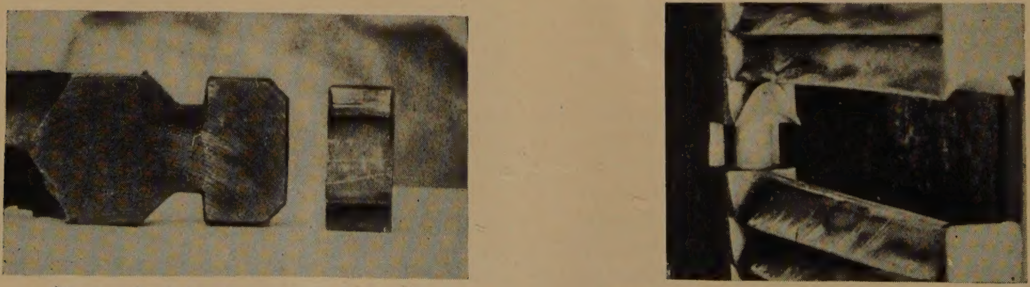
The Idea of Wave Motion

About the same time, certain types of vibration of standing wheels were investi-



7th stage bucket broken at neck of dovetail
12,500-kw., 1500-r.p.m., 8-stage

6th stage bucket broken at neck of dovetail
12,500-kw., 1800-r.p.m., 9-stage



9th stage bucket broken at neck of dovetail
7500-kw., 1800-r.p.m., 9-stage

18th stage buckets broken at root of blade and at neck of dovetail. 20,000-kw., 1800-r.p.m., 23-stage

Fig. 11. Details of Bucket Failure Due to Axial Vibration

gated by means of sand pictures. The usual form was a series of vibrating segments symmetrically arranged about the circumference and extending into the web but separated by radial lines of quiet called nodal radii or nodes. These will be discussed in detail later.

Windage Theory

In connection with the study of strains about holes in wheel webs, a series of India rubber wheels as shown in Fig. 14 had been made and photographed by means of instantaneous electric sparks while rotating at high speed. In order to produce representative stresses throughout the rubber disks, metal weights were attached about the circumference, shaped to simulate the loading due to turbine bucket blades.

In running these wheels it was discovered that above certain definite speeds their circumferences developed a form of wave motion as shown in Fig. 15. This was examined by means of an intermittent spark either synchronized with the speed of rotation or adjusted to occur at slightly greater or less frequencies. The shapes of the waves and their rates of progress were thus examined visually, and it was found that these waves progressed around the wheel in the direction of rotation, but at a less speed than the speed of the wheel, that is, relative to the wheel itself the wave was travelling backward, seemingly driven by the windage encountered like the fluttering of a flag.

This gave rise to the so-called windage theory that the waves were developed and driven backward in the wheel by the atmosphere in which it was revolving. Investigation of this theory led to the rotation of paper disks in a vacuum. The wave motions, clearly observable in an atmosphere disappeared as

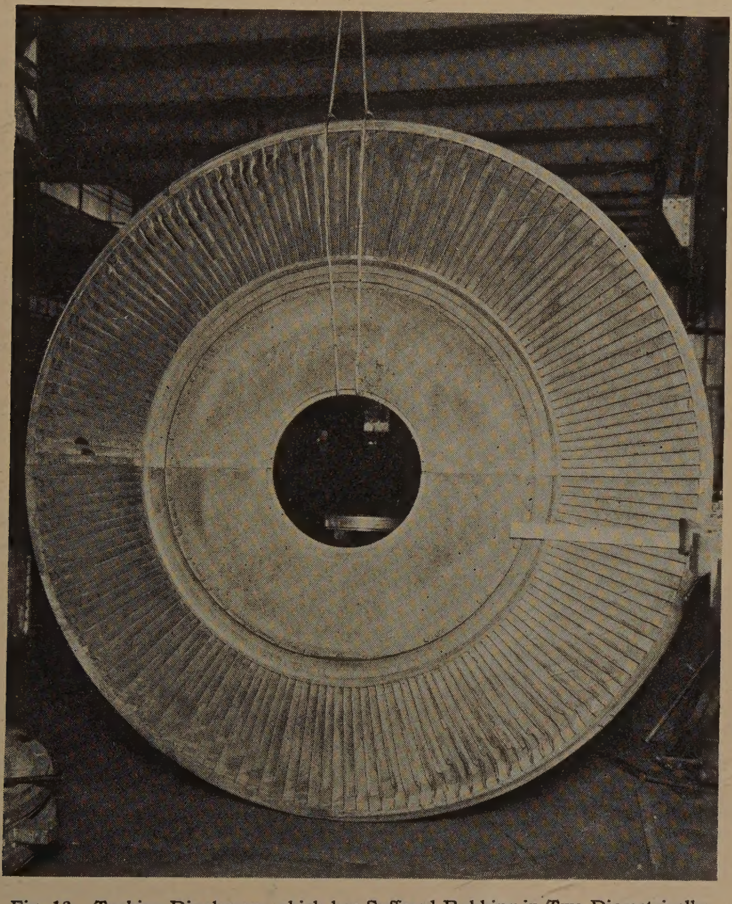


Fig. 12. Turbine Diaphragm which has Suffered Rubbing in Two Diametrically Opposite Regions; 17th Stage of 30,000-kw., 1800-r.p.m., 17-stage Turbine

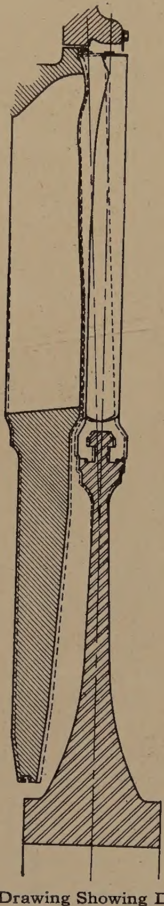


Fig. 13. Drawing Showing Depth of Rubbing at Worst Parts of Fig. 12. All of the buckets on the wheel were rubbed alike to the shape shown

the atmosphere became rarefied. These experiments were immediately extended to exceedingly thin steel disks which were found to behave in a similar manner. Since the waves could not exceed the speed of the actuating wind without encountering resistance, they could only be supported in wheels whose natural frequencies corresponded to waves travelling at less speed than the speed of rotation. It was therefore made a condition of design of turbine wheels that the natural wave speed should exceed the speed of rotation wherever possible. This resulted in a general thickening of all wheels being designed for turbines constructed at that time to give them a greater rigidity to withstand the supposedly detrimental effect of the wind action.

Windage Theory Abandoned

Oscillograph coils were placed in two large turbines and during operation complete surveys of these machines showed that several stages developed wave phenomena of the same general characteristics. Turbine wheels were thus shown capable of supporting travelling waves. In these turbines the waves appeared only when the turbine carried more than a certain definite load and died out when the load was removed. However, waves were found to be travelling in the wheel in a direction opposite to the rotation of the wheel and at a higher speed, which could not be explained by the windage theory.

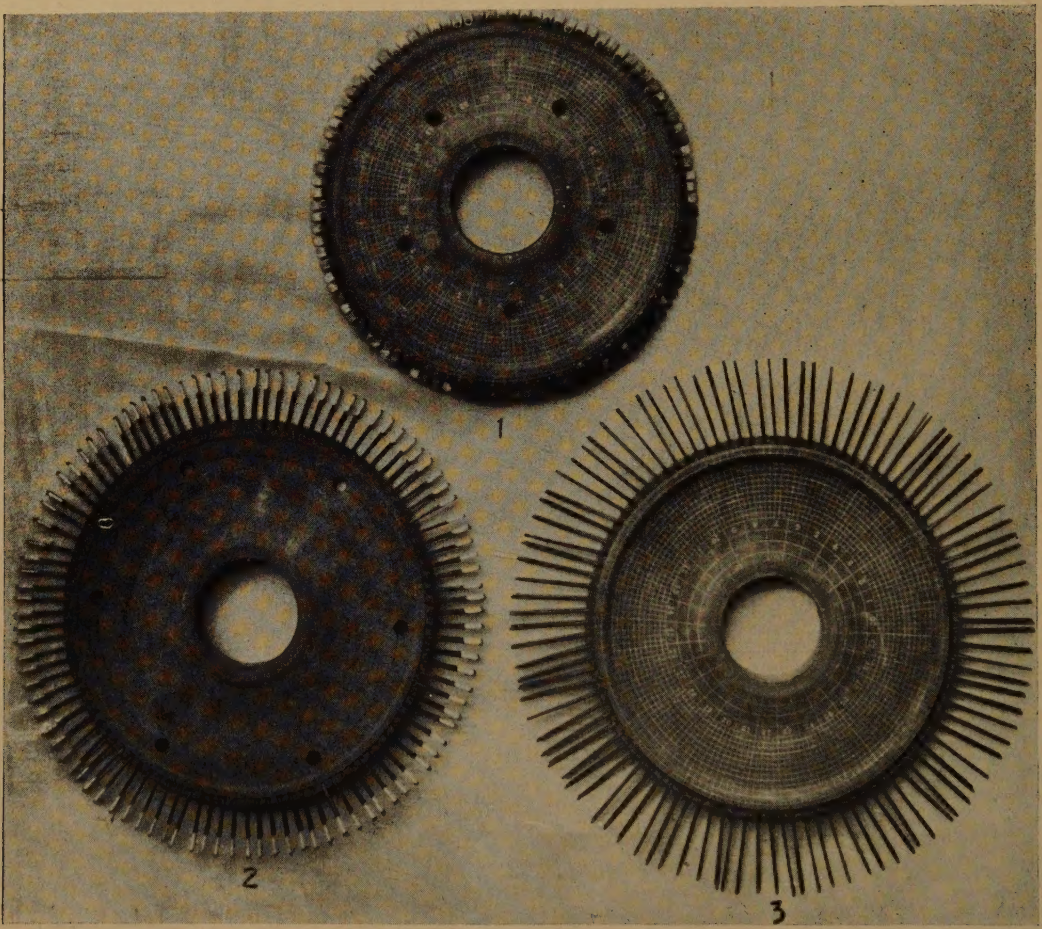


Fig. 14. India-rubber Wheels Used to Examine the Strains About Holes in the Web

Wave Phenomena Records Made from a Thin Steel Disk

The first oscillograms taken in which a revolving coil was used were made with a thin sheet metal disk. Fig. 16 is typical of the type of oscillograph record obtained. The upper curve *A* is taken by a coil stationary in space and opposite the rim of the disk; it shows that there is a wave motion in the disk. The smoother portion of the curve corresponds to the part where the wheel disk is most remote from the coil, and the more disturbed portion indicates that the wheel rim is in close proximity. These more disturbed portions, which may be called beats, occur at a much lower rate than the speed of rotation so that the corresponding wave crest producing them must have progressed around in the disk itself.

Curve *B* is taken by a coil made to revolve with the wheel but mounted on a separate arm. When this coil passed near the supporting pillow block a voltage was induced which makes the long narrow lines in the curve, there being one of these for each revolution. The V-shaped points in this record show that a transverse motion is taking place in the wheel disk, resulting in change of clearance between the disk and the revolving coil. It can be shown that this is not in any sense synchronous with revolutions but simply records a transverse vibration of the wheel itself.

Curve *C* is taken from the 40-cycle alternating-current line and is here used as a timing wave. The small interruptions in this wave are made by a contact on the shaft carrying the model steel disk and they correspond therefore to revolutions of the disk.

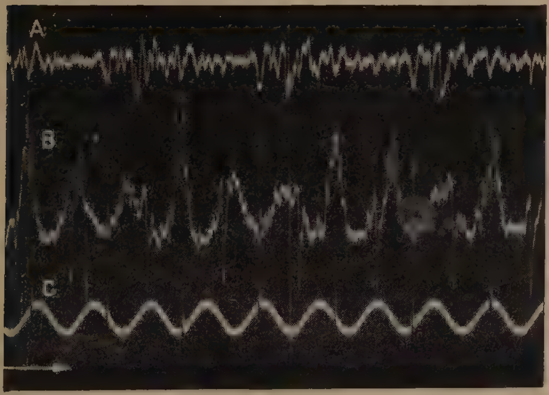


Fig. 16. One of the First Oscillograms Recording Disk Vibrations. Trace *A* was recorded by a stationary coil. Trace *B* by a coil revolving with the disk, and Trace *C* is a 40-cycle timing wave. Model disk wheel of thin sheet metal

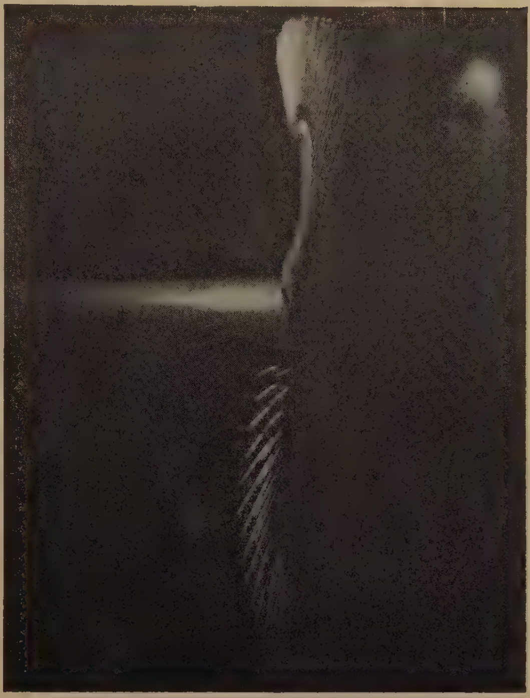


Fig. 15. Photograph by an Instantaneous Spark of an India-rubber Wheel Exhibiting Wave Phenomena at a Speed of 650 r.p.m.

The record shown in Fig. 17 was made by a thin steel disk revolving slowly. This disk was vibrated by means of an alternating-current magnet carried on a rotating arm at the same speed. The upper record *A* was obtained by a fixed coil while the lower record *B* is a 40-cycle timing wave. The irregularities in the record obtained by the

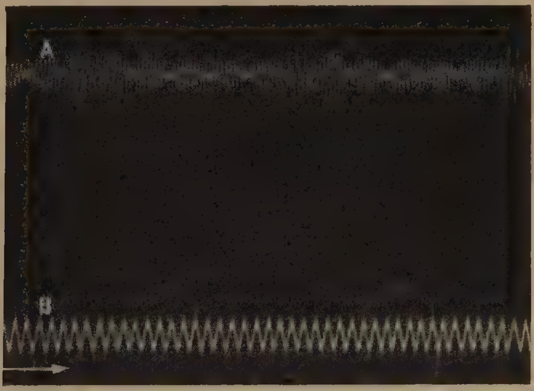


Fig. 17. Record of 6-Node Vibration in a Thin Steel Disk Excited by an Alternating-current Magnet Revolving with the Wheel. Trace *A* was recorded by a stationary coil. Trace *B* is a 40-cycle timing wave

TABLE II

EARLY SUMMARY OF WHEEL AND BUCKET TROUBLES

The methods by which such troubles have been eliminated are described in Parts II and III of this article

Rating	Stage	Date Trouble Occurred	Trouble	Nodes	Backward Speed of Wave R. P. S.	Operating Speed R. P. S.
35000–1500–20	19	1918	Wheel	4	25.6	25
15000–1800–9	9	1918	Wheel	4	27.9	30
15000–1800–9	9	1919	Wheel	4	29.5	30
5000–1800–7	3	1920	Wheel	6	28.5	30
3000–Variable–4	3	1921	Wheel	6	48.1	48
30000–1500–12	11	1921	Wheel	4	25.2	25
20000–1800–12	10	1917 1919 1920	Buckets	8	30.2	30
30000–1800–17	13	1918	Buckets	8	30.1	30
30000–1800–17	17	1918	Buckets	4	32.6	30
45000–1200–21	21	1918	Buckets	4	19.8	20
7500–1500–8	2	1919	Buckets	6	25.4	25
5000–3600–5	2	1919	Buckets	4	57.4	60
30000–1800–17	11	1920	Buckets	8	29.6	30
30000–1800–17	12	1920	Buckets	6	28.8	30
15000–1800–23	21	1920	Dovetail	4	29.5	30
10000–1800–9	8	1921	Buckets	8	30.6	30
35000–1500–22	17	1921	Buckets	6	24.2	25
30000–1500–20	14	1921	Buckets	8	25.9	25

stationary coil are caused by the passage of the rotating exciting magnet of which, it will be noted, the electrical frequency is one-half the mechanical frequency. This record, briefly, shows wheel vibration of the 6-node type including both forward and backward waves which will be explained in the next part of this article. This record is reproduced in the fifth edition of Stodola's "Steam Turbines."

Recognition of Wheel Critical Speeds

Subsequently Table II was compiled which definitely established the importance of the wave stationary in space, that is, the wave progressing backward in the wheel at the speed at which the wheel rotates forward. This speed is called a *wheel critical speed*. In making a statement of the importance of this phenomenon, it should not be assumed that it is the only type of wheel vibration of a serious nature. This type of vibration causes by far the largest number of failures, in fact, so large a fraction that breaks caused by other types of vibration may fairly be treated as exceptional.

At this time the importance of obtaining test data on full-sized wheels under actual operating conditions was first fully appreciated. This resulted in the design and construction of the first wheel-testing machine.

Subsequent efforts have been directed not only toward the routine testing of wheels but also toward the investigation of various special phases of vibratory phenomena.

In order to give a more adequate comprehension of the subjects discussed and the meanings of the terms used, Part II (which will be published in the July issue of the Review*) is devoted to "An Exposition of the Nature and Theory of Vibration in Turbine Wheels."*

Part III (which will appear in the August issue of the Review*) is devoted to a description of "The Methods of Design and Testing for the Protection of Turbine Disk Wheels from Axial Vibration." This procedure, established for the manufacture and production of turbine wheels, has definitely eliminated difficulties of the type enumerated in the historical outline.*

(*To be Continued*)

Improving Central Station Service by the Application of Current-limiting Reactors to Distribution Feeders

By David K. Blake

Central Station Engineering Department, General Electric Company

Poor service is unattractive to a purchaser, is a continual source of complaint, and invites rigorous regulation or even competition. Good service is eagerly sought and thus sells itself. Of the many factors which influence the quality of electric service, the minimizing of the voltage drop under short-circuit conditions is deserving of more attention than it has hitherto received. Current-limiting reactors furnish the means of maintaining a high standard in this respect, but so far comparatively little use has been made of them outside of generating stations. This condition is undoubtedly due to a lack of appreciation of their usefulness in distribution feeders as well, in consequence of which the following article has been written to point out the decided advantages that are obtainable by their installation in this class of circuits.—Editor.

Central Station Service

Central station companies sell not only electricity but, what is more important, electric service. The quality of electric service is very much dependent upon maintaining approximately normal voltage continuously. The company which designs its system so as to reduce service interruptions to a minimum renders good service; but the company which in addition designs its system so as to maintain approximately normal voltage during all load variations and which maintains the voltage as high as possible under all short-circuit conditions renders better service. Service interruptions are reduced to a minimum by the proper application of spare equipment and circuits, of oil circuit breakers and relays, and of sectionalizing switches. Normal voltage is maintained during load variations by designing the system with the minimum voltage drop that is economical and by the use of generator voltage regulators, transformer tap-changing equipments, and induction feeder voltage regulators. The voltage is maintained as high as possible under short-circuit conditions by the proper application of current-limiting reactors.

Application of Current-limiting Reactors in General

Up to the present time current-limiting reactors have been most generally used at the generating stations. Current-limiting reactors located in the main bus limit the flow of power from one bus section to the other, while reactors located in the transmission feeders limit the amount of power flow into a feeder fault. Limiting the amount of power flow into a fault by the use of reactors has the advantage of maintaining voltage on the bus section and feeders not in trouble. Without reactors the station bus voltage would fall almost to zero in case of a short circuit. This would be reflected over the entire system and would have a tendency to permit synchronous apparatus to fall out of step and possibly cause a complete shut down of the station or system. Limiting the amount of power flow into a fault by the use of current-limiting reactors has the additional advantage of reducing the duty on oil circuit breakers and reducing the heating and electromagnetic forces on the buses, disconnecting switches, cables, and current transformers.

Necessity of Large Distributing Transformer Substations

Substations step the transmission voltage down to the distribution voltage which in this country is usually either 2300 volts, 3-wire, or 2300/4000Y volts, 4-wire, with an appreciable amount of 4600 volts, 3-wire. The load density in large cities is rapidly increasing, consequently making it necessary either to increase the size of substations or else use a large number of small substations with automatic switching equipment. The latter method is equivalent to higher voltage distribution since one 13,200-volt feeder can supply several small automatic substations rated from 600 to 2000 kv-a. in capacity, as shown in Figs. 1 and 2. It still seems, however, that service and economy will require large substations in congested areas ranging from 7500 to 50,000 kv-a. in capacity. The larger the substation the more important it is that a short circuit on a feeder shall not reduce the voltage on the other feeders any more than necessary. Also, the larger the substation the more is the company warranted in spending money to improve the service given to its customers.

Effect of Feeder Reactors on Distribution Bus Voltage

The curves shown in Fig. 3 are based on the assumption that the system is large enough in kilovolt-ampere capacity to maintain approximately normal voltage on the high-voltage side of the transformer in case of a short circuit on the low-voltage side. This is approximately true for large systems, particularly when low-voltage feeder reactors are used. It is easy to see from the diagram in Fig. 3 that, in case of a feeder short circuit near the distribution bus, the voltage on this bus will be approximately equal to the normal voltage minus the reactive drop through the transformer. For example, suppose we assume we have a substation of 15,000 kv-a. capacity with 200-amp. feeders. The transformers have an 8.5 per cent reactive drop when supplying 15,000 kv-a. and the feeders have reactors which give a 3 per cent reactive drop at 200 amp., 4000 volts, or approximately 1400 kv-a. The feeder regulators have about 1 per cent reactance which makes a total of 4 per cent reactance in the feeder circuit at 1400 kv-a. or about 43 per cent reactance at 15,000 kv-a. Adding this to the reactance in the transformers gives a total reactance of 51.5 per cent to the short circuit. The short-circuit kilovolt-amperes then are

$$\frac{100}{51.5} \times 15{,}000 = 29{,}100 \text{ kv-a.}$$

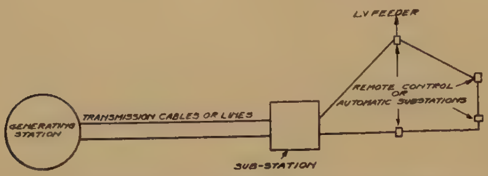

LV FEEDER
REMOTE CONTROL OR AUTOMATIC SUBSTATIONS
GENERATING STATION
TRANSMISSION CABLES OR LINES
SUB-STATION

Fig. 1. Small Indoor or Outdoor Substations Supplied by Loop Feeders

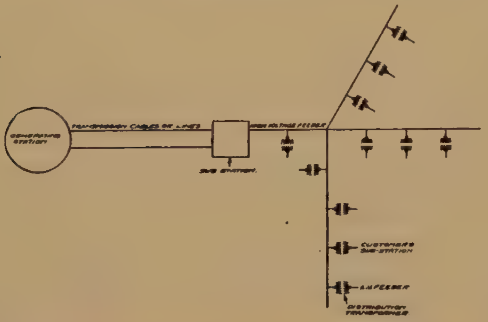


Fig. 2. High-voltage Radial Feeder Supplying Distribution Transformers and Customers' Substations

Therefore, the reactive drop through the transformer is

$$\frac{29{,}100}{15{,}000} \times 8.5 = 16.5 \text{ per cent.}$$

The voltage on the distribution bus then is,

$$100 - 16.5 = 83.5 \text{ per cent.}$$

The reactive drop is subtracted numerically from the normal voltage because the power-factor of the short-circuit current is almost zero. Suppose that the substation is connected to a radial system and that three 5000-kv-a. underground transmission feeders equipped with 5 per cent reactors supply it directly from the generating station. It will be more accurate to consider the voltage at the generator bus as maintained at normal, in case of a low-voltage feeder short circuit, instead of the high-voltage substation bus. By adding the 5 per cent reactance of the transmission feeders and performing similar calculations as before, we find that the short-circuit kilovolt-amperes are 26,500 and the distribution bus voltage is 76.2 per cent. This however is based on the assumption that the substation is carrying no load; but if we assume full load at 0.80 power-factor the regulation, including transmission feeder reactors and transformers, will be about 8 per cent. This is usually compensated for by regulating equipment at the generating station or by means of taps on the substation transformers. Therefore, in case of a low-voltage feeder short circuit, the distribution bus

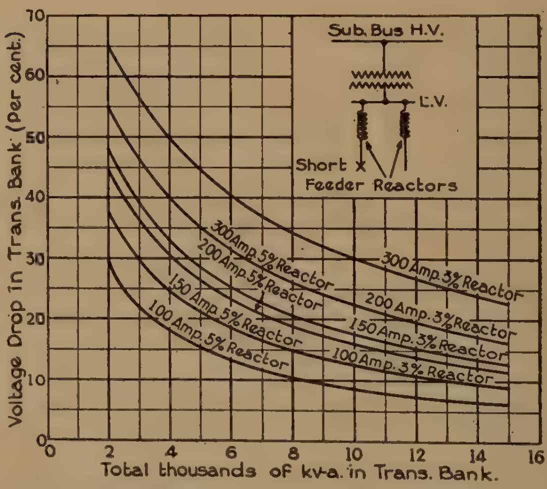


Fig. 3. Curves Showing Voltage Drop Through Various Size Transformer Banks with Short Circuit on Feeders with Current-limiting Reactor and Voltage Regulator. Bus not sectionalized

voltage will be approximately 84 per cent of normal voltage at full load 0.80 power-factor.

It is obvious that this improves considerably the service given to the consumers. They will not suffer from the dropping out of alternating-current contactors or under-voltage releases as the contactors drop out around 60 to 70 per cent of normal voltage and under-voltage releases at about 50 per cent voltage. Induction motors carrying full load or even 25 per cent overload will not pull out of step or stall because the maximum torque is about 250 per cent with normal voltage, and with 84 per cent voltage, it is

$$0.84^2 \times 250 = 176 \text{ per cent.}$$

Since the excitation of the synchronous motor does not vary with the voltage applied to the stator, as does the induction motor, the synchronous motor pull-out torque varies directly with the applied voltage instead of as the square of the voltage as in the induction motor. A continuous rated synchronous motor then will fall out of step at approximately 67 per cent voltage when delivering full-load torque at rated power-factor. It seems, then, that it is desirable to hold the voltage on the distribution bus above 67 per cent in order to reduce to a minimum the interruption of any part of a customer's service when a short circuit occurs on a feeder to which the customer's service is not connected. Induction motors, alternating-current contactors, and under-voltage releases will continue in service on lower voltages than 67 per cent. The synchronous motor, therefore, is the limiting feature. From the curves in Fig. 3 it is found that a 3 per cent reactor gives excellent voltage conditions for a

300-amp. circuit, 10,000-kv-a. substation and above,
200-amp. circuit, 6000-kv-a. substation and above,
150-amp. circuit, 5000-kv-a. substation and above,
100-amp. circuit, 2000-kv-a. substation and above.

This, of course, does not take into account the transmission feeder reactors at the generating station. The effect of these reactors should be included if the system connections are such that these reactors will have an appreciable effect on the results.

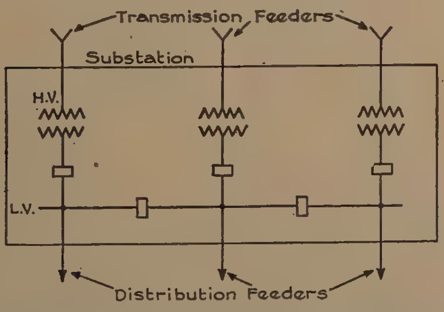


Fig. 4. Sectionalizing Distribution Bus with Oil Circuit Breakers to Reduce Short-circuit Currents and Disturbances

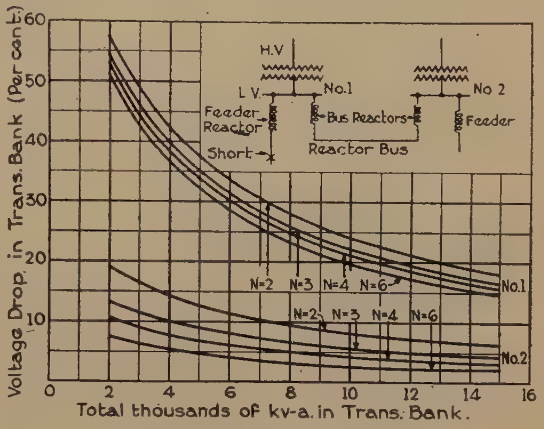


Fig. 5. Curves Showing Voltage Drop Through Various Size Transformer Banks with Short Circuit on Feeders with Current-limiting Reactor and Voltage Regulator. Bus sectionalized with Reactors

The minimum size of substation in which it is warranted to install current-limiting reactors to give better service depends on several factors, the most important being the nature of the load, the territory served, and the company's policy with regard to the service it renders. It does seem, however, that substations 10,000 kv-a. and larger would certainly justify the installation of current-limiting feeder reactors.

In order to limit the concentration of power in the substation, both the high-voltage and low-voltage buses of very large capacity substations are sectionalized. The sectionalization may be accomplished without bus reactors, by operating a bus section and a transformer bank as a unit, as shown in Fig. 4, with no connection between buses except under emergency or light load conditions. With this scheme automatic switching equipment may be provided to have each transformer supplying its own section under heavy load and one bank of transformers supplying all sections under light load conditions with the other transformers disconnected. For intermediate loads the automatic equipment will determine the number of transformers in service and the number of sections tied together. Sectionalization with bus reactors may be accomplished as shown in Fig. 5 where the voltage conditions are appreciably improved over those shown in Fig. 3. The curves are plotted for a 300-amp. feeder with a 3 per cent reactor. The upper set of curves marked *1* gives the voltage drop in the transformers to which the short-circuited feeder is connected. The lower set of curves marked *2* shows the voltage drop through the other transformers.

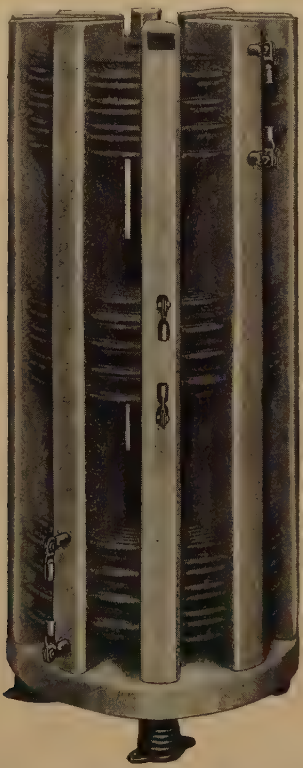


Fig. 6. Three-phase Cast-in Current-limiting Reactor for Circuits up to 2500 Volts

From Fig. 3, a 300-amp. circuit with a 3 per cent reactor gives a drop of 22.5 per cent for a 15,000-kv-a. bank; while Fig. 5 gives an 18 per cent drop on section *1* when using two 15,000-kv-a. banks. The drop on the other section is about 6 per cent. If four sections are used, then the drop on section *1* is 15.5 per cent and on the other sections 3 per cent.

In Fig. 6 is shown a three-phase cast-in current-limiting reactor for use in circuits up to 2500 volts. Figs. 7, 8, 9, 10, and 11 show single-phase reactors arranged in three-phase groups for circuits above 2500 volts. The reactors shown in Figs. 10 and 11 may be used where minimum height and width are required. The curves in Fig. 12 show the variation of the voltage regulation of a circuit with the per cent reactance. If a 3 per cent reactor is added to a circuit which has an 0.80 power-factor load, the increased regulation from curve *C* is found to be about 1.8 per cent. This is generally taken care of by the induction regulator.

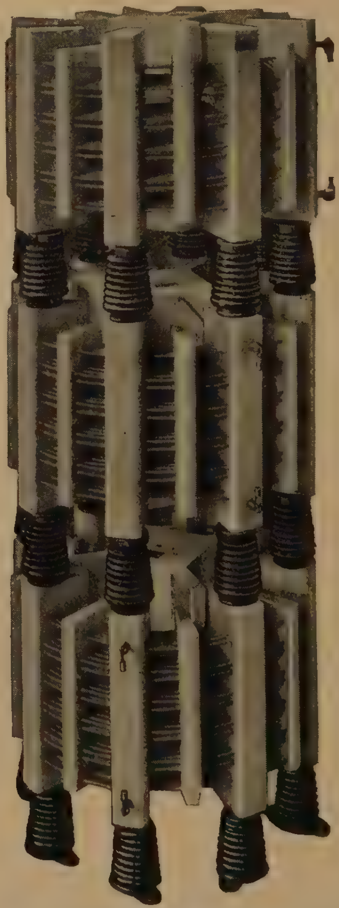


Fig. 7. Vertical Arrangement of Three Reactors for a Three-phase Circuit

Effect of Feeder Reactors on Substation and Line Equipment

In addition to maintaining the distribution bus voltage, the feeder reactor has many other advantages such as reducing the duty on oil circuit breakers and fuse cutouts, reducing the

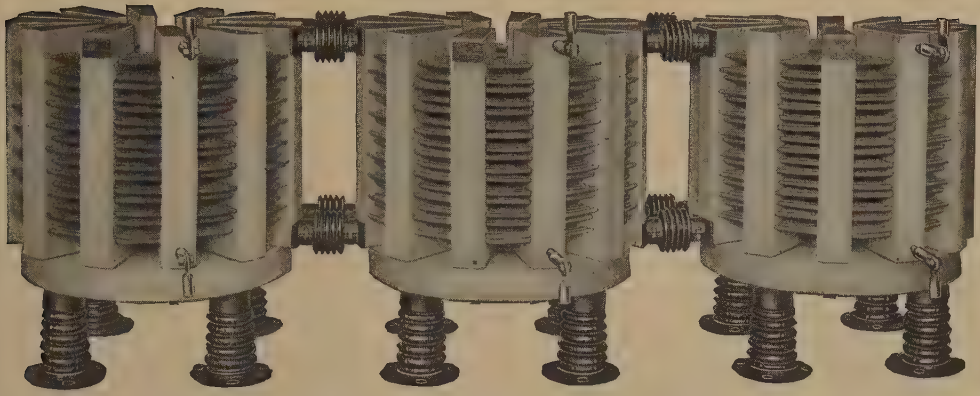


Fig. 8. Straight Line Arrangement of Three Reactors for a Three-phase Circuit

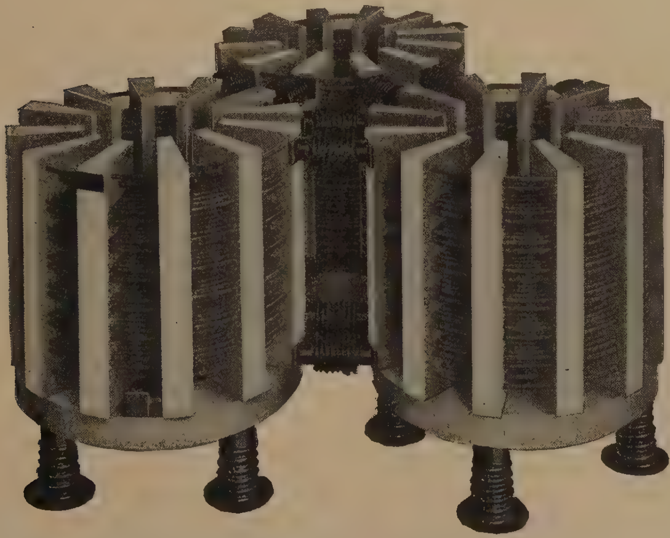


Fig. 9. Triangular Arrangement of Three Reactors for a Three-phase Circuit

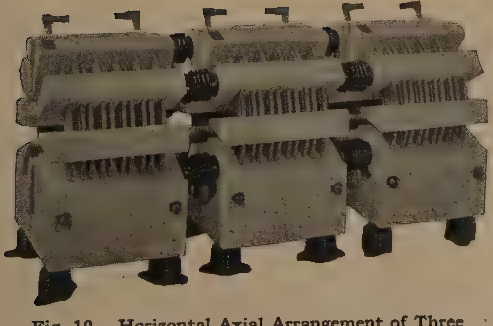


Fig. 10. Horizontal Axial Arrangement of Three Reactors for a Three-phase Circuit

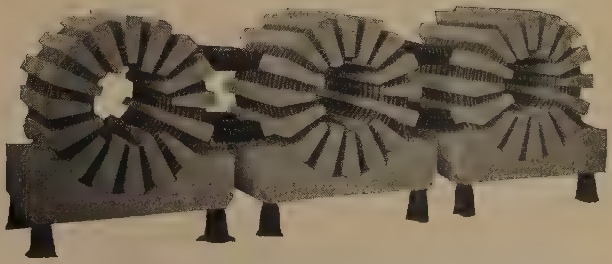


Fig. 11. Another Horizontal Arrangement of Three Reactors for a Three-phase Circuit

heating and electromagnetic forces on buses, cables, disconnecting switches, current transformers, and induction regulators. The reduction in duty on the oil circuit breakers may or may not be taken advantage of to reduce the investment in breakers. For example, a 10,000-kv-a. substation with a 4000Y-volt distribution bus will give a maximum r.m.s. symmetrical short-circuit current of approximately 9400 amp. when a short circuit occurs on a 200-amp. feeder with induction regulators. This would require a circuit breaker* having an interrupting capacity of 9400 amp. at 4500 volts. The use of a 3 per cent reactor in this circuit would limit the maximum r.m.s. symmetrical current to 25 times normal, considering the 1 per cent reactance in the regulator, or to 5000 amp. regardless of the capacity of the substation. This would permit the use of a breaker which has an interrupting capacity of 6000 amp. at 4500 volts. The price of the latter breaker is approximately $80 less than that of the former breaker, yet it seems that it is better engineering not to take advantage of the $80 difference, but to use the higher interrupting capacity breaker at a considerable reduction in duty and still have a breaker that is of sufficient rated interrupting capacity to open a short circuit in case of the remote possibility of the reactor failing. Suppose the circuit is rated at 300 amp. with an induction regulator. Then the maximum symmetrical short-circuit current for a 10,000-kv-a. substation is 11,100 amp. which requires a breaker that has an interrupting capacity of 14,500 amp. at 4500 volts. In this case the use of a 3 per cent feeder reactor would limit the maximum r.m.s. symmetrical current to 25 times normal or 7500 amp. regardless of the capacity of the substation. This would permit the use of a breaker costing approximately $290 less. Some engineers may consider the difference of approximately $290 worth taking advantage of while others would prefer the larger breaker. It is obvious that this reduction in oil circuit breaker investment is greater the larger the substation.

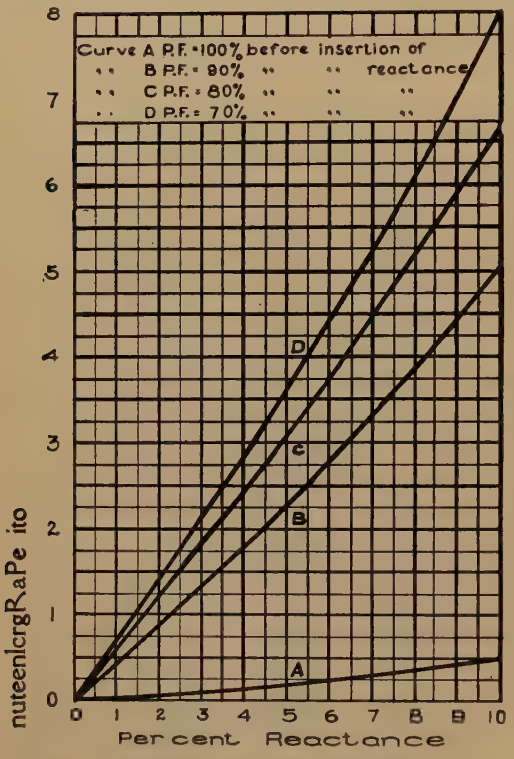


Fig. 12. Variation of the Voltage Regulation of a Circuit with the Per Cent Reactance

Induction regulators and some auto-transformers cannot be economically designed to stand short-circuit currents with normal voltage sustained on the primary because the impedance of the windings is so low and consequently the short-circuit current so high that it would be very expensive to construct the auto-transformer or regulator with sufficient strength to withstand the electromagnetic forces due to the high short-circuit current. Referring to Figs. 13 and 14, it is easy to see how the impedance of the auto-transformer or regulator is much less than in the transformer. In Fig. 13 the impedance of the primary and secondary are in series, while in Fig. 14 the impedance of the primary and secondary are in parallel under short-circuit conditions. In the case of step-down units, the transformer secondary is short-circuited at secondary voltage, while the auto-transformer or regulator is short circuited at the higher primary voltage. The short-circuit currents in induction regulators heat the copper windings which may damage the insulation and produce enormous electromagnetic forces between the rotor and stator, which may strain the shaft and damage the mechanism. These forces also exist between the coils and may weaken or damage the insulation. To the weakening of the insulation by the heating and electromagnetic forces may be added the high voltage induced in the primary winding during short circuit by the application of primary voltage to the secondary winding. This induced voltage may be nearly ten times normal in a 10 per cent regulator. The failure of the insulation of the regulator filled with oil produces in it a short-circuit arc, which may rapidly generate gas or ignite a gas mixture, resulting in an explosion that may scatter burning oil through the station. A more complete discussion of the effects of short-circuit currents on induction regulators is given in Mr. E. F. Gehrkins' book on "The Induction Voltage Regulator,"* page 437. Manufacturers of induction regulators guarantee their regulators to withstand safely the short-circuit current on a feeder which gives 25 times normal symmetrical r.m.s. amperes short-circuit current. The use of a 3 per cent feeder reactor with induction regulators, which have approximately 1 per cent reactance, will limit the short-circuit current to 25 times normal symmetrical r.m.s. amperes on a system regardless of its kilovolt-ampere capacity.

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*In order to draw a fair comparison in this example, the circuit breakers mentioned are those of one manufacture; being actually those that would be selected for the purpose from the standard line of General Electric equipment.

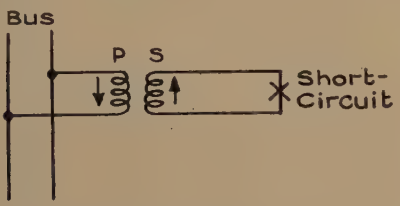

Fig. 13. Short-circuit Current on Transformer of 1:1 Ratio

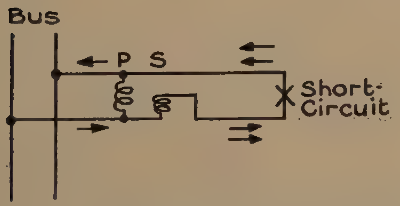

Fig. 14. Short-circuit Current on Auto-transformer or Induction Regulator of 2:1 Ratio

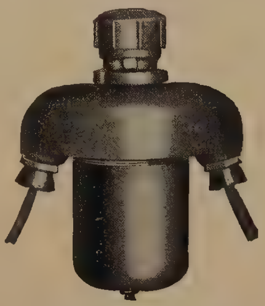

Fig. 15. Pole-type Heavy Service D&W Oil Fuse Cutout

Automatic oil circuit breakers and fuses are used on the distribution system for sectionalizing purposes and for protection of transformers. Current-limiting reactors in the distribution feeders at the substation will reduce to a considerable extent the duty on these devices. The breakers and fuses connected to a 200-amp. 4000-volt distribution circuit with induction regulators, supplied by a 10,000-kv-a. substation, may be required to open a short-circuit current of 9400 amp.; while those on a 300-amp. circuit supplied by a 30,000-kv-a. substation may be required to open 19,000 amp. Installing 3 per cent reactors in these circuits will reduce the maximum possible r.m.s. symmetrical short-circuit current to 5000 amp. for the 200-amp. feeder and to 7500 amp. for the 300-amp. circuit. This brings the short-circuit current well within the tested interrupting capacity of some fuses on the market and within the rated interrupting capacity of the heavy service pole-type D&W oil fuse cutout shown in Fig. 15. The 200-amp. cutout is rated at 5000 amp. while the 300-amp. is rated at 7500 amp. interrupting capacity at 2500 volts. The D&W cutout could therefore be used in place of the manually operated oil circuit breaker where the latter is used for short-circuit protection. The D&W cutout although not designed or recommended for switching purposes is sometimes used to open moderate loads when necessary. Where they are used for such purposes it must be expected that eventually the contacts will have to be replaced because of their becoming burned. After a number of operations this pitting will increase the resistance between the contacts enough to cause them to overheat at normal or part load which would probably cause failure. The D&W cutout, therefore, would be used only in place of an oil circuit breaker where it is not required to switch a circuit under load, or when switching under load is seldom required, such as in emergency cases. One D&W cutout will be required for each phase wire; therefore, in a three-wire branch there will be required three 200-amp. 2500-volt heavy-service pole-type cutouts which will have a total price of approximately one-third that of an automatic manually operated triple-pole

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*Published by the General Electric Company, and indexed sa Publication Y-1677.

pole-type oil circuit breaker with 11,500-amp. interrupting capacity at 2500 volts. There is also a saving in weight as the three pole-type cutouts have an approximate weight of 463 lb., while the pole-type oil circuit breaker weighs about 825 lb. Therefore, the use of a 3 per cent feeder reactor at the substation in a distribution circuit with induction regulators makes it possible to use the pole-type oil circuit breaker shown in Fig. 16, on circuits up to 250 amp., 4000 volts, and the D&W cutout on circuits up to 300 amp., 4000 volts, on any system capacity without exceeding their rated interrupting capacity. The lower cost and weight of the D&W cutout makes it feasible to extend the degree of sectionalizing to a point which would not be feasible with pole-type oil circuit breakers. In applying the 2500-volt D&W cutouts to circuits from 2300 to 4000 volts with grounded neutral, care should be taken on single-phase taps above 2300 volts that each line is equipped with a cutout. The normal ampere rating of the cutout should at least be the same as the ampere rating of the 3 per cent reactor while the fuse link in the cutout may be rated at the required value.

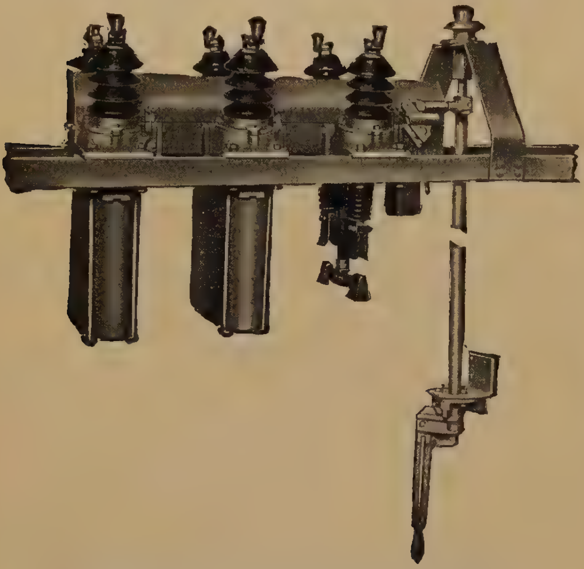

Fig. 16. Outdoor Oil Circuit Breaker; Triple-pole, Single-throw, 15,000-volt, 400-amp. Breaker open, one tank removed

Automatic subway type oil circuit breakers requiring an interrupting capacity equivalent to the pole-type breakers will have a cost from three to five times as much as the pole-type breakers. The subway breakers will require at least a 36-in. diameter manhole, will have a number of joints with possibility of leaks, and will take up considerable vault space. Breakers of still higher interrupting capacity will be necessary if feeder reactors are not used. The feeder reactor will permit the use of the heavy service D&W cutout shown in Fig. 17 without exceeding its rated interrupting capacity. In most cases it would be possible to use the D&W cutout in place of the oil circuit breaker. The saving by the use of three 200-amp. 2500-volt heavy-service subway type D&W cutouts instead of a subway breaker would easily pay for the installation of 3 per cent feeder reactors. Thus, one installation of D&W cutouts per circuit, in place of the oil circuit breaker, would save enough money to install a set of reactors, thereby improving the service to customers without any additional investment.

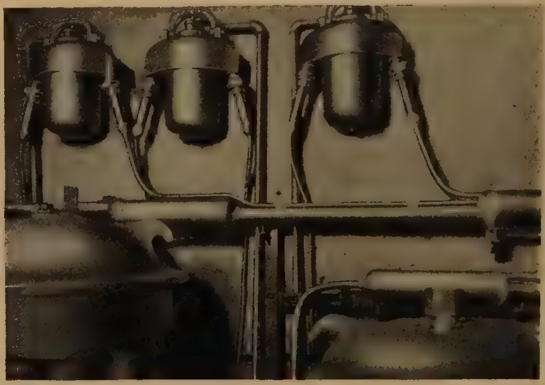

Fig. 17. Subway Installation of Heavy Service D&W Oil Fuse Cutouts

Clear Fused Quartz Made in the Electric Furnace

By Edward R. Berry

Thomson Research Laboratory, General Electric Company

Clear fused quartz is a more remarkable substance than glass in many respects; for in addition to the properties which these two materials possess in common, fused quartz has certain additional and very useful characteristics. For instance, it is serviceable up to 1000 deg. C. without injury, has a remarkably small coefficient of thermal expansion, will transmit ultra-violet light with but little absorption, etc. The method by which clear fused quartz can now be produced on a commercial scale is described in the following article, which was presented as a paper at the Forty-fifth meeting of the American Electro Chemical Society at Philadelphia, April, 1924.—Editor.

Introduction

It is the purpose of this article to present some of the recent results of the development of clear fused quartz and to focus attention on some of the surprising properties of this material. The art of making fused quartz dates back to 1839 when Gaudin, in France, discovered the general thermal properties of fused quartz. A number of advances have been made in the art since that date by various investigators; but most of this work has been concerned with the opaque variety of fused quartz usually made from sand. It is only during the past twenty-three years that the development of clear fused quartz has made very rapid progress.

It has been possible for many years to make fused quartz of a high quality in small sections and lengths by hand labor in the ordinary blast flame, using gas and oxygen. This has been done by piecing together small sections of crystal in the flame; or by adding silica powder from time to time until the piece has grown to the heating limit of the flame, an obviously slow and expensive process. From this step in the development of the art to the point where very large masses of equal quality can be made has been a long and difficult one. In the last few years the advances made by the process described in this article have been so rapid and far-reaching that there seems to be no limit now to the size of high-quality clear fused quartz which can be made, except that which may be imposed by mechanical difficulties.

Method of Fusion

When it is desired to obtain fused quartz of the quality which is illustrated in this article, it is necessary to start with the very highest quality of raw material, of which there is none better than water clear crystals. It is much more difficult to make fused quartz of this high quality from sand even if its purity exceed 99 per cent. The rock crystal used in this work is water clear and contains probably less than two-tenths of one per cent impurities. The surfaces are often encrusted with iron oxide and other foreign material and the crystal itself can be seen to contain clusters of small bubbles. The crystal is therefore washed in acids, and then broken up and the unsuitable pieces discarded.

There are two distinct steps in the preparation of tubes, rods, ribbons and cane; the most important of which is the initial fusion. The clean quartz crystals, which are of various sizes, are packed as densely as possible in a graphite or carbon crucible so that during the cracking of the crystals, which is bound to occur as the temperature is raised, the parts cannot separate and allow any small amount of gas which may be present to enter the many crevices and thus form bubbles. Those tightly packed crucibles are placed in a modified vacuum furnace and the temperature raised as quickly as possible to the melting point. During this fusion the pressure in the furnace is kept as low as possible. The time required for fusion will vary with the conditions and in all cases no more than 45 minutes is necessary. The energy rate of fusion is from 3 to 8 kilowatt-hours per pound of quartz, and the loss of quartz due to volatilization is negligible compared with other charges. The result of this first fusion is a clear, transparent slug containing comparatively few bubbles ranging in size from a pin point to 2 or 3 mm. in diameter. Whether these bubbles have been formed by a gas or by silica vapor, it must be remembered that they have been formed at a temperature of about 1800 deg. C.; and consequently their pressure at room temperature is very small. This slug is now placed in another graphic crucible which is suspended in a vertical carbon tube furnace. A graphite piston which just fits the crucible is placed on top of the fused quartz slugs and a weight is placed on top of a plunger attached to the piston. The slugs are again brought to fusion, the bubbles are practically collapsed and by the action of the weight the quartz is extruded in the various forms, such as rods, tubes, ribbon, etc. This material is practically free from bubbles, but because of limiting dimensions it may become necessary to re-work some of this, which is accomplished by the usual bench methods with an oxygen-illuminating-gas flame.

When it is desired to obtain large blocks as free from bubbles as the tubing, cane, and ribbon, another operation is necessary. As before, the quartz is fused in a vacuum furnace which, however, is also designed to withstand very high pressures. As soon as the material is fused, the vacuum valve is closed and the pressure in the tank is brought up to some value, depending on the object in view, in less than a minute. This pressure collapses the bubbles and makes it possible to obtain very large slugs freer from bubbles than many kinds of the best optical glass.

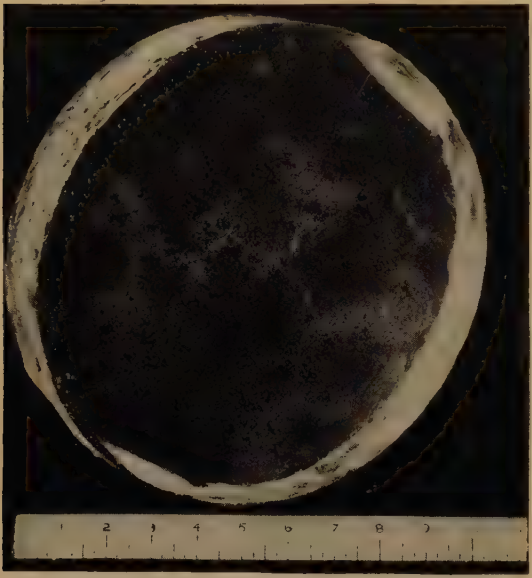

Fig. 1. Clear Fused Quartz Disk; 11½ In. Diameter, 2½ In. Thick

Previous attempts to reduce the bubbles by continued heating above the melting point resulted, after a certain stage, only in excessive loss of silica by volatilization. We have fused quartz at initial pressures of 600 lb. per sq. in., atmospheric pressure, and less than ½ mm. of pressure. In the first case the mass was practically opaque; at atmospheric pressure it was considerably improved although much inferior to the present quality of quartz; and under vacuum conditions a large mass can be produced, which from the standpoint of number of bubbles is very satisfactory.

Not the least of the difficulties encountered in this development has been that in connection with the furnace equipment. The vacuum furnace in particular had to be greatly changed and enlarged with the result that we now have probably the largest vacuum furnace in daily use capable of operating at low pressures. Then, in addition to this, the furnace had to be so constructed as to withstand repeatedly on the cover a total pressure of over 1,000,000 lb. (about 600 tons), and of course as the size of the furnace increases these difficulties are multiplied. Special attention must be paid to the design of the resistor unit, to the thermal insulation, to even heat distribution, to the cooling of the terminals, and to the many other factors which presented themselves in the use of these two extremes in pressure

When the quartz crystal is heated between 500 and 600 deg. C., it undergoes a remarkable physical change, cracking into small pieces sometimes with explosive violence. This is due to the difference of coefficient of expansion along the two axes subjecting the crystal to great strain, and to the decrepitation caused by the presence of water and liquid carbon dioxide held in vast numbers of minute cavities throughout the crystal. The only advantage therefore in using large crystals for fusing lies in the greater ease of keeping the charge free from foreign material before the different particles begin to coalesce.

Hereaus has heated crystal quartz in very small pieces, about the size of a nut, very slowly so that no cracking occurs and, consequently, no bubbles are included in the vitreous pieces. Herschkowitsch, on the other hand, has arrived at about the same result by accelerating the heating process so that a film of vitreous material is formed on the outside and prevents air from penetrating to the center, even though cracks may develop. As a matter of fact these processes, while interesting, are subject to very sensitive control and are impractical where large masses are to be fused.

To obtain masses quite free from bubbles, it has been found best to raise the temperature rapidly to 1400 or 1500 deg. C. at which point the pieces begin to coalesce. At about 1750 deg. C. the quartz is thoroughly fused though it is still very viscous. In fact, the viscosity is high even though the temperature be well over 2000 deg. C. Vaporization of fused quartz is rapid at 1600 deg. and at

1750 deg. C. the loss due to evaporation is very great. Further increase in temperature results in no great gain in fluidity.

Homogeneity of Fused Quartz

The difficulties of obtaining perfectly homogeneous fused quartz free from striae strain, bubbles, and double refraction must be apparent to anyone who has worked on this problem, and discouraging perhaps to those who have tried to buy such material. It is a little too early to state in what quantities such a product can be produced, but we have manufactured quartz of this quality which contained only two or three bubbles visible to the eye. This quality, however, has not as yet been placed on a commercial basis.

Properties and Applications of Clear Fused Quartz

The fact that for a great many purposes clear fused quartz can be used up to 1000 deg. C. without injury; that its coefficient of thermal expansion is so small as to make it almost negligible; and that it will transmit light rays even into the extreme ultra-violet with very little absorption, gives to it a great utility value—not only to the scientist but the manufacturer as well.

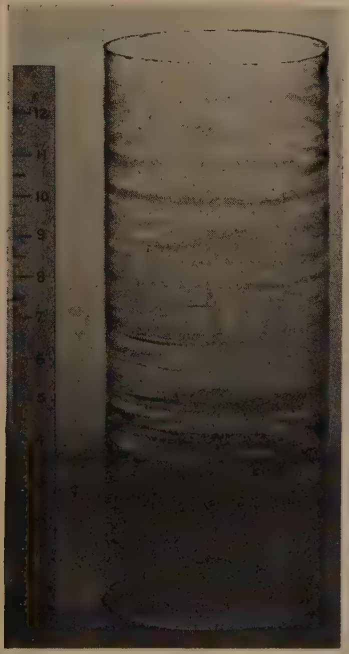

Fig. 2. Clear Fused Quartz Tube; 5 In. Diameter, 13 In. Long, $\frac{1}{16}$ In. Wall

The specific gravity of clear fused quartz is 2.21. Its coefficient of thermal expansion is 58 by 10^{-8} which is about 1/17 that of platinum and 1/34 that of copper; so small that a rod of quartz one meter in length will expand only about six-tenths of a millimeter for a 1000 deg. C. rise in temperature. The small probability of fracture under sudden changes in temperature, because of this property, makes it especially desirable for many uses. Furthermore, where it is used as a mirror in reflecting telescopes this very small expansion or contraction with change in temperature causes almost no distortion of the image and, consequently, much greater accuracy is made possible. This property also makes the grinding of a lens or mirror less tedious and costly, as it is not necessary to await the cooling of the shape in order to get the desired curve. It is possible to heat a tube of clear fused quartz, say ⅝ inch in diameter, to the melting point and plunge it into ice cold water without fracturing.

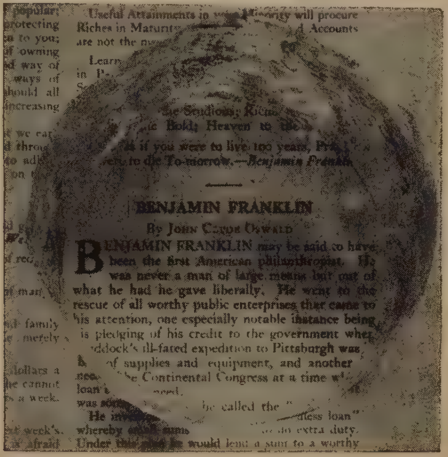

Fig. 3. Clear Fused Quartz Slug; 3 In. Diameter, 9 In. Long

Its index of refraction for the *D* line is 1.459, and while its dispersion is higher than optical glass it is more constant because of the smaller effects due to temperature changes. If the rays which have entered are nearly parallel to a rod of quartz they are totally reflected internally and on account of this can pass around curves, unless too sharp. This property, coupled with a very small absorption loss, makes it possible to transmit light through very great lengths of curved rod or tubing with very little loss. A rod of this fused quartz one meter long will emit at one end about 93 per cent of the total visible light passed into the other end. For the better grades of optical glass the highest percentage transmitted under the same conditions is not more than 65 per cent.

The ordinary run of quartz made by this process and used in the fabrication of quartz mercury-arc lamps will transmit light wavelengths as low as the 1850 Å line in the ultra-violet. From the opposite end of the spectrum the heat rays also are transmitted with little loss. For example, if one end of a fused quartz rod 12 in. long is heated to incandescence, it will be found very uncomfortable to hold the finger over the other end, although one may comfortably grasp the rod a few inches from the heated zone.

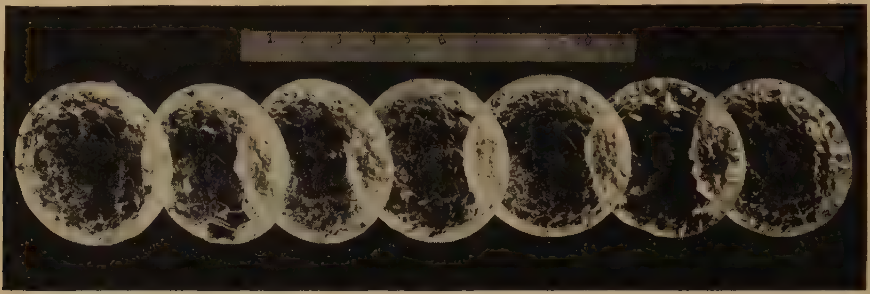

Fig. 4. Seven Clear Fused Quartz Condensing Lens Blanks; 4½ In. Diameter

Clear fused quartz is the only known material which can be obtained in quantity and which is transparent to ultra-violet rays. The medical profession is consequently utilizing this material more and more in its application of ultra-violet light for therapeutic purposes.

By the process here described it is now possible to make tubes, rod, ribbon, and cane in lengths of 30 ft. and in shorter lengths of diameters up to eight inches. Blocks have been made up to 11½ inches in diameter and 6 inches thick having comparatively few bubbles, and these widely separated, comparable in general appearance to the best quality of optical glass. Such material is suitable for prisms, lenses, and for use in instruments where the visible ray is an important factor.

Constant progress in this development is being made and it is hoped that perfect homogeneity can be made the rule rather than the exception. It is expected that for most optical work this quality of the present material will be entirely satisfactory.

Projection Lenses

Fused quartz lenses of 4½ in. diameter have been for several months very successfully operated on test in motion-picture projection machines, using currents as high as 150 amp. and where glass lenses cracked almost daily.

Thermometers

It is well known that in the ordinary glass thermometers there is an appreciable lag in the glass, so that successive readings in a descending scale are inaccurate. To test the extent of this we have placed a standard glass thermometer and a quartz thermometer of our own construction in the same bath and raised the temperature to 515 deg. C. and then lowered it again to 0 deg. C. In this

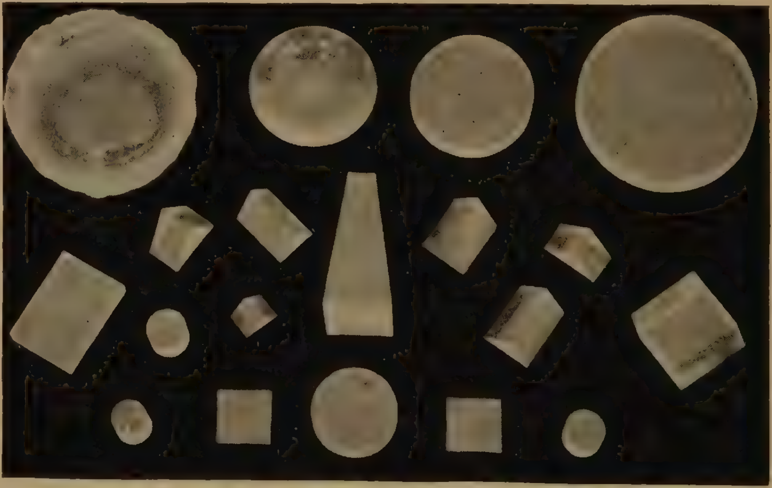

Fig. 5. Lenses, Prisms, Cubes, etc., of Clear Fused Quartz

particular case the mercury in the glass came back to four divisions below the zero mark, whereas the mercury in the quartz returned exactly to its original calibrated mark at zero. While the capillary in the quartz tubing is not exactly uniform throughout its entire length, it is so uniform that a calibration of the tube over its whole length would eliminate any inaccuracies due to the slight non-uniformity.

Tuning Forks

As a standard of pitch the tuning fork is about the only appliance in use. Temperature changes affect the pitch of the hardened steel fork, however; and, what is more important, the work which has ~~to~~ be done in adjusting these steel forks to the desired pitch by grinding or otherwise working them results in changes in elasticity and dimensions that cause a disturbance of the pitch note. A tuning fork of quartz is not subject to these changes to any appreciable degree.

This work has all been carried on in the Research Laboratory of the General Electric Company at Lynn, and in presenting this description the author wishes to express his appreciation of the efforts of Mr. L. B. Miller and Mr. P. K. Devers who, in a large measure, were responsible for the good results obtained.

How Some Problems in Radio Have Been Solved

By E. F. W. Alexanderson

Chief Consulting Engineer, Radio Corporation of America

Most engineering accomplishments are not even initially attained without "hard plugging." In radio development, the story has been somewhat different. Many of the accomplishments were for the first time obtained as the result of chance, and most of the hard plugging followed in order to overcome this element of uncertainty, a particularly troublesome component of which has been the forces of Nature over which there is no control. In describing how some of the problems of commercial radio communication have been solved, Mr. Alexanderson treats them under four headings—efficiency and cost of radiation; wave propagation, absorption, and fading; atmospheric disturbances; and speed of commercial signalling. He shows how hard plugging endeavor along scientific lines has made possible the spanning of our globe by American-built stations that twenty-four hours a day the year round furnish thoroughly dependable radio communication service.—Editor.

The real romance in any development lies in the pioneer stages. When long-distance radio communication was first put to important use, during the war period, many thrilling episodes occurred.

One of these took place in a station that had been hastily reconstructed and forced into the service of maintaining communication with France while we were yet building and experimenting in radio. Originally the station had been of the Marconi type but had become obsolete, and its reconstruction primarily consisted in setting down a high-frequency alternator and building a primitive transmitting plant around it. Trouble soon developed in the antenna insulation. Usually an insulator would blow up with an explosion but sometimes it would give a warning by a flickering light. The station was strongly guarded by marines who were quick on the trigger and one dark night the guard saw a flickering light in one of the wooden shacks which was used to house the outdoor tuning coils. He thought it was an enemy spy and would not take any chances so he peppered the shack with his automatic rifle. After a little while the insulator exploded and the station was dead. This gave the marine convincing proof that somebody had planted a bomb.

Firearms played no part, however, in the final solution to this problem of insulator breakdown. It was technical knowledge acquired by scientific investigation that furnished the means of eliminating the trouble. This is but one such incident.

The development of commercial radio in all its phases has afforded an unusual opportunity for the application of scientific engineering methods. In most other branches of engineering there are many precedents to help or hinder the engineer in his choice of methods. In radio communication there were but few such precedents; practically every problem was a new one and had to be solved by new means. In addition to this element of newness, there was the additional complication of having to deal with forces of Nature which are not under control and therefore subject to the law of chance. At the outset these laws of Nature were very little understood and all of them are not yet entirely known. For instance, what are the causes of fading and exceptional increase of signal strength, or periodic fluctuation of signals? It can only be stated that these phenomena are observed to have something to do with the change from daylight to darkness and that they are more pronounced at the shorter wavelengths. The hypothesis of the Heavyside layer has been introduced as an explanation but is not altogether convincing.

That great enemy of radio communication, atmospheric disturbance, so-called "static," is by this time well understood and under control. It is really this fact that makes commercial radio communication at all possible.

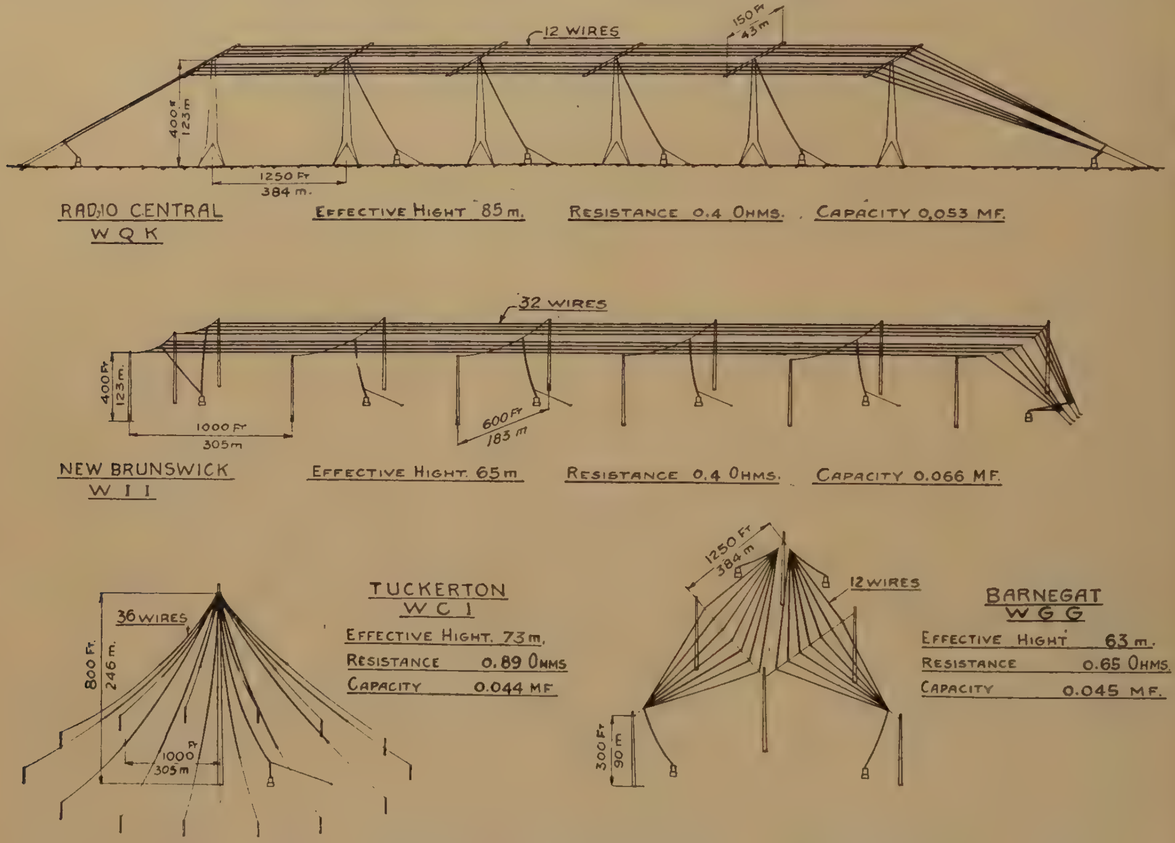

Fig. 1. Types of Antennas Used in the Atlantic Coast Stations of the Radio Corporation

To bring about order and dependability in the transmission of radio signals, it has been necessary to take into account the law of probability and averages. This can be readily understood by whose who are radio amateurs or broadcast listeners. When a clear signal is received from across the continent, this interesting fact is related to friends. Similarly, when the sportsman catches a big trout, he makes mention of it as an event. Nevertheless, professional fishermen succeed in providing fish for the market with great regularity. Thus it is the aim of the radio engineer to explore the sea of the ether, to weather its storms, and to provide a continuous service of communication day and night.

The transoceanic radio station is a power station. Its input is kilowatts and its output is words. The problem of radio engineering is to establish the relation between kilowatts input and words output. This relation between kilowatts and words is a chain comprising four separate links which are being studied by specialists in the following subjects:

(1) Efficiency and cost of radiation.
(2) Wave propagation, absorption and fading.
(3) Atmospheric disturbances.
(4) Speed of commercial signalling.

Efficiency and Cost of Radiation

The first subject deals with the radio power station and the antenna. Fig. 1 shows four types of antennas which are used in the system of the Radio Corporation of America. Three of these are adaptations of old structures, but the fourth, the Radio Central antenna, is designed from the ground up. The radiation efficiency of an antenna depends upon the effective height, the ground resistance, and the wavelength. In antennas for long waves most of the energy is absorbed locally and only a small proportion is radiated.

The object of modern antenna design has been to get maximum radiation for a given antenna investment as well as a maximum radiation for a given power consumption. These two requirements are contradictory and, as usual in design, a compromise must be arrived at. A high radiation efficiency can be obtained only by the use of a very expensive antenna. There is a third requirement that the operating potential must be kept within practical limits. The best compromise between these requirements has been obtained in the long multiple tuned antenna with moderately high towers operated at high potential. The Radio Central antenna has twelve ground connections distributed over a distance of three miles, and has 300 miles of wire buried in the ground. Through these devices the ground resistance has been reduced to 1/20 ohm. Antennas of types previously used had ground resistances of about 2 ohms. The losses in the ground have thus been reduced to a different order of magnitude.

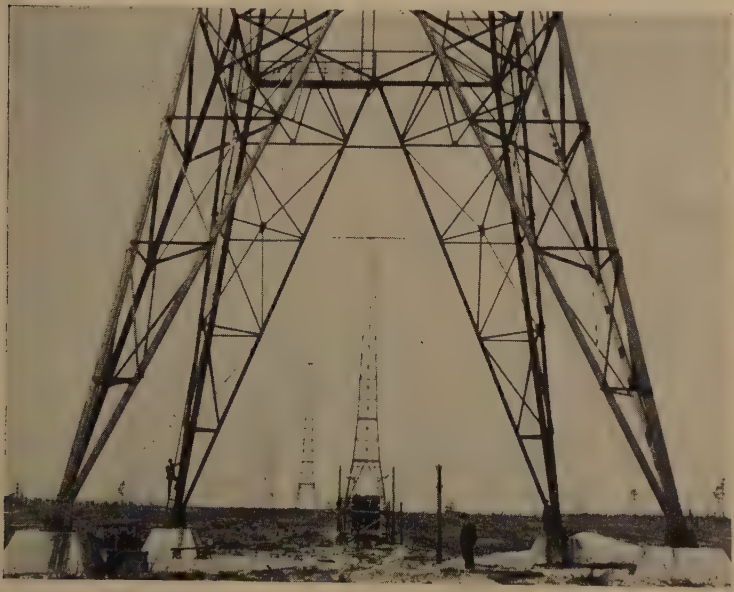

Fig. 2. Looking Through the Base of One of the Antenna Towers of the Radio Central

Fig. 3. Looking Along the Aisle on the Cross-arm of One of the Radio Central Towers

The practical measure of the power of a transmitting station is not the energy radiated but the product of the amperes in the antenna and the effective height of the antenna. This unit of radiation is called the meter-ampere. The radiating power used in a typical trans-oceanic telegraph station is about 50,000 meter-amperes, whereas a representative broadcasting or ship station has the power of only a few hundred meter-amperes. The distance that can be covered under normal daylight conditions by a transmitting station is about proportional to the number of meter-amperes used provided that a wavelength has been selected which is suitable for communication over such a distance.

Wave Propagation, Absorption, and Fading

The second subject is wave propagation. The longer the wavelength the greater is the cost of antenna structure and the lower is the radiation efficiency. From this point of view it would seem that long waves would be undesirable. If communication were desired only during the hours of darkness, this would be so, but in commercial communication the daylight hours are the most important and during those hours the absorption of the short waves is so great that better and more economical communication is obtained by the long waves. For each distance there is a certain wavelength which gives the best compromise between absorption and radiation efficiency.

The absorption of short waves is particularly high over dry sandy ground. It is also frequently observed that the variable character of intervening land and water breaks up short wave transmission into several paths which eventually meet again in such a way that the waves recombine. The waves will thus unite sometimes in phase and cause an increase of signal strength, and sometimes out of phase thus causing periodic fading of the signal. Practical experience can be summed up in the rule that the most economical wavelengths for reliable daytime communication over any distance is about one five-hundredth of the distance.

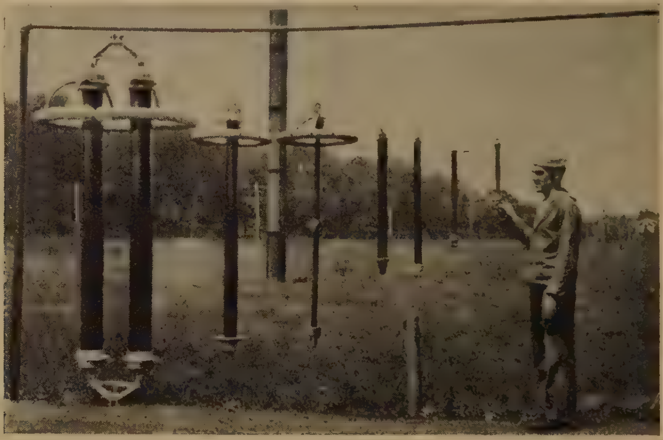

Fig. 4. Some Insulators in the Early Stages of Development

Atmospheric Disturbances
"Static"

The third subject deals with the atmospheric disturbances. Our modern receiving system eliminates about nine-tenths of the disturbances but the residual which is not eliminated determines the speed of reception by the law of inverse proportionality.

Sufficient knowledge has now been accumulated on these subjects to enable new radio communication circuits to be designed with the same deliberateness as we design a dynamoelectric machine. The designer starts at the receiving end and gathers his facts and reasons backward in order to determine what power, wavelength, etc., the transmitting station should have in order to serve the purpose most economically.

This can best be illustrated by an example. The first step in planning a radio circuit is to make measurements of atmospheric disturbances at the places where the signals are to be received. These measurements should extend throughout the season of the year when reception is most difficult.

At this point it may be of interest to explain the modern conception of atmospheric disturbances and the means devised to control them.

Any such disturbance was originally called "static" because it was assumed to be of the nature of static electricity. The hypothesis which is the basis of modern work is different, however. The ether is imagined to be a disturbed ocean with waves of every length rolling in from all directions. These waves are of the same nature as the signal wave. Those disturbing waves which are of different wavelength from the desired signals can be shut out by the same means as is used for shutting out other signals, that is, by tuning. But the disturbing waves which have the same wavelength as the desired signal are in all respects of the same nature and pass through the tuning system like the signal.

Elimination of "Static"

It is thus apparent that if some ground for discrimination can be found other than wavelength we would have a higher order of selectivity than is obtainable in the ordinary tuned receiver. Such a principle has been found and has proved to be one of the most important developments in radio communication. If a receiver is constructed which is sensitive to waves coming from only one direction, then waves from any other direction can be shut out even if they have the same wavelength. This is the principle of directive reception on which the receiving stations of the Radio Corporation are based.

Each successive step in increasing directivity of the receiving system has shown marked improvement in its capacity for handling traffic. The development of the central receiving station at Riverhead, Long Island, has already reached the point where the signals from Europe are received on an antenna system 30 miles long and the signals from South America on another antenna system 20 miles long. The antenna consists of two telegraph wires mounted on telegraph poles.

The basic element of this receiving system is the so-called "wave antenna" or "Beverage antenna" which has been described in various publications. In its simplest form it consists of a single wire, one wavelength long, mounted on telegraph poles or even laid on the ground. This antenna is sensitive to waves from only one direction. A wave is started by the ether wave in one end of the wire and travels along the wire with the velocity of light. In the meantime, energy is continuously added to the wave in the wire from the ether wave which travels alongside it, so that the wave in the wire continuously increases and reaches a maximum at the opposite end of the wire where the receiving set is located.

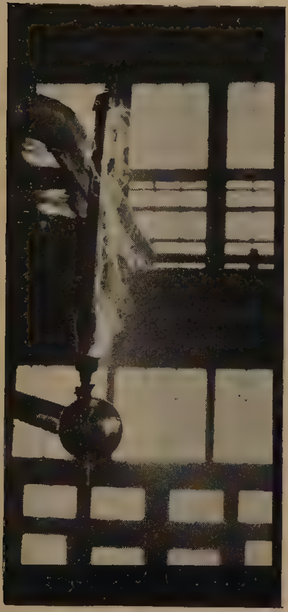
Fig. 5. Arc-over an Early Type of Insulator Under Test

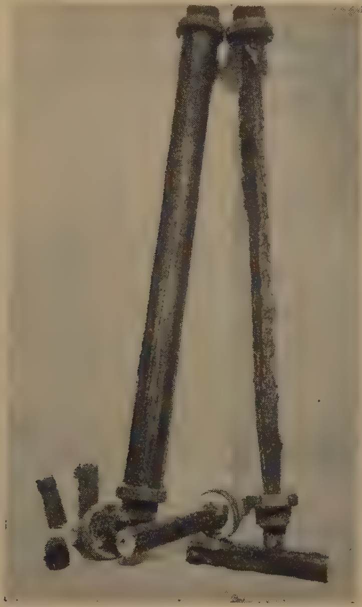
Fig. 6. An Insulator of an Early Type, and One Tested to Destruction

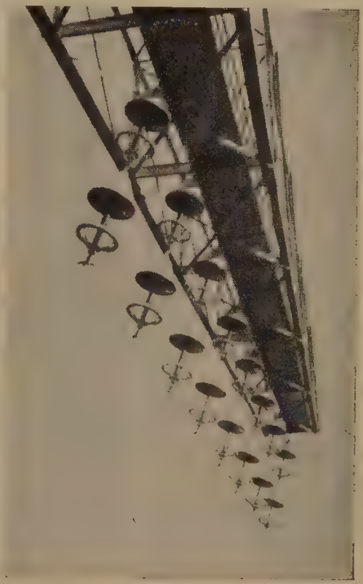
Fig. 7. Modern Type of High-voltage Antenna Insulators, Hung Two in Series

Selection of Receiving Site

Static usually originates from the land side and thus if the signal comes from the ocean it is possible to design the receiving system so that it eliminates the static and retains the signal. In one exceptional case, it was found after sending an expedition to the place which had been planned for a radio station that static and signal came from the same direction and that radio communication would have been impossible for several hours a day. A new receiving site was then investigated where conditions were found to be favorable. The adoption of this location necessitated the redesign of the whole system in such a way that the signal reached the ultimate destination after passing two sides of a triangle, the relay station being situated at one of the points of this triangle. Two lines of favorable direction were thus substituted for one line of unfavorable direction; just like a sailboat which requires two tacks to arrive at a point straight to the windward.

This is a very unusual case but it shows that a practical solution can be found even under the most unfavorable circumstances.

Speed of Commercial Signalling

The fourth subject deals with the speed of reception. It has been observed in radio telegraphic communication that the maximum signalling speed is directly proportional to the ratio between the wave amplitude and the amplitude of the atmospheric disturbances. The reason for this is the following:

The shortest element of telegraphic signal is a dot. The higher the signalling speed the shorter is the dot. Thus while the wave amplitude is kept constant the total energy contained in the dot sign is inversely proportional to the speed of signalling. When the strongest single atmospheric impulse prevalent at any particular time contains as much energy as a dot in the telegraphic code, it may be mistaken for a dot, or it may break up a dash into two dots; thus causing false telegraphic signs. It is, therefore, necessary to maintain a speed of signalling in which the total energy of a dot is somewhat greater than the maximum energy of a single atmospheric impulse. Thus if the wave amplitude is doubled the length of the dot may be shortened to one-half. This explains why in practice the telegraphic signalling speed is proportional to the wave amplitude and also why it is inversely proportional to the atmospheric disturbance.

Measurement of Signal and Static

It can thus be seen that it is important in developing new systems of communication to have accurate data on the intensity of atmospheric disturbances. Methods have, therefore, been developed for measuring signal strength as well as atmospheric disturbances in absolute quantities. The unit of measurement is microvolts per meter. The meaning of this term is "millionth parts of volts per meter effective height of the receiving antenna." If, for instance, a signal induced has an absolute amplitude of 100 microvolts per meter, this can be ascertained by using a receiving antenna of ten meters effective height and introducing an artificial signal in this antenna of 1000 microvolts generated by a calibrated oscillator. If the artificial signal of 1000 microvolts has the same loudness as the incoming signal we conclude that the antenna is exposed to a field strength of 1000 microvolts. The effective height of the antenna was ten meters, thus the signal strength was 100 microvolts per meter effective height of the antenna. Measurements made in this way are easily reproducible.

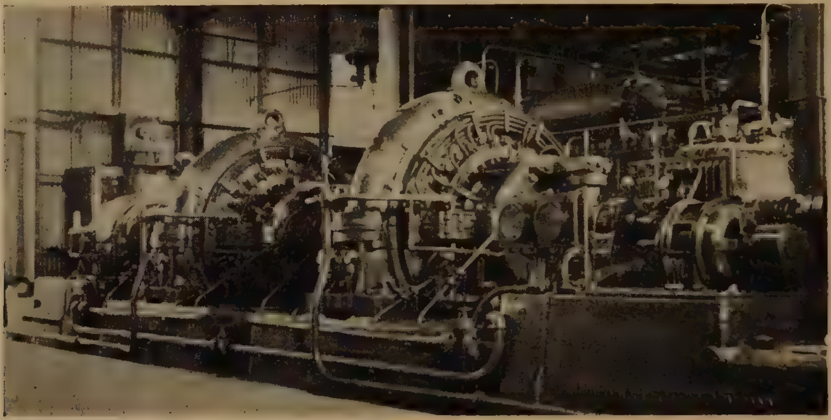

Fig. 8. The Output of these Radio-frequency Alternators, Varying Many Times a Second from Zero to 200 kw. in Accordance with the Dots and Dashes of the Telegraphic Code, is controlled Directly from the Radio Central Operating Room shown in the Frontispiece of this issue

Measuring instruments have been developed by which charts can be made to show by polar curves the intensity of the static in all directions. Such charts are made for every hour of the day. Their examination will show that portions of the static can be eliminated by unidirectional reception and what the intensity will be of the static which cannot be eliminated. Assume that this investigation shows that the total static for the afternoon hours of the summer is 500 microvolts per meter. Reception under such conditions without the unidirectional receiving system would be totally impossible. Assume, however, that the polar charts show that only 10 per cent of the static falls within the quadrant from which the signals are to be received. The portion of the static which cannot be eliminated has then an effective intensity of 50 microvolts per meter. A transmitting station that can give a signal intensity of 50 microvolts per meter could then be expected to handle traffic at a rate of 20 words per minute during those worst hours of the day and at a higher rate during the remaining hours. If this is not sufficient to handle the expected volume of traffic, it may be decided to use a signal intensity of 100 microvolts per meter with the expectation of receiving at a rate of 40 words per minute during the worst hours.

strength ten times as great, which would mean a radiated energy one hundred times as great. Such a use of brute force would not be practical nor economically possible. These figures are representative for most cases of transoceanic communication.

There is now a chain of American-built stations surrounding the earth which are either in operation or in process of construction. When the chain is completed, it will be possible to link them together, and send a signal which will automatically be relayed from station to station and circle the earth with the velocity of light. If it is sent from New York it can be relayed over San Francisco, Honolulu, Shanghai, Sweden, or Poland, and back to New York.

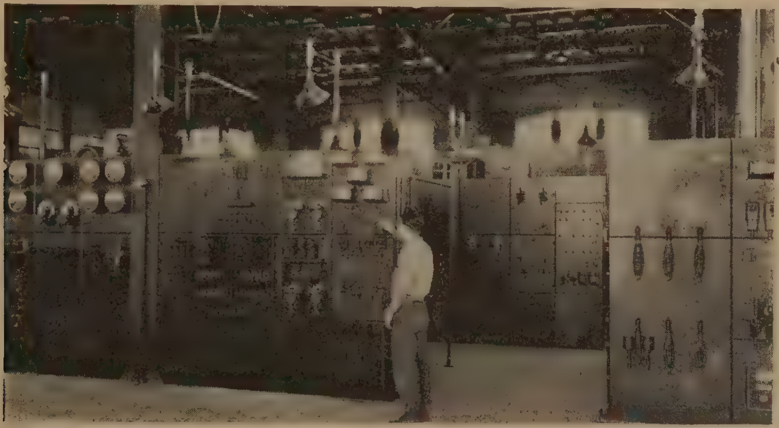

Fig. 9. Switchboard for the Complete Control of the Equipment in a Radio Power Station. The telegraphic signals from the Radio Central operating room are automatically relayed through this board to the alternators. Manual control is used only for starting and stopping the machines

Prediction of Traffic Capacity

Extensive data are now available on transmission efficiency from which it can be determined with fair accuracy what radiating power is needed in the transmitting station in order to produce the desired signal intensity at the receiving station. Assume that a signal strength of 100 microvolts per meter requires a transmitting station of 50,000 meter-amperes. This would be a station of the size used in transatlantic service. On the other hand, assume that no attempt was made to reduce static interference by unidirectional reception and that it was expected to receive a communication of the same continuity and reliability by increasing the signal strength. This would require a signal

Conclusion

The fact that radio telegraphy has now definitely attained the commercial stage does not mean that the end of its development has been reached. By the continued application of scientific engineering principles to the solution of its problems, as they arise, radio telegraph service will grow to fill a greatly extended field of utility. But this is not all. The knowledge which has been gained in making radio telegraphy dependable is now available for application to broadcasting. There is reason to believe that the utilization of the same principles will go a long way toward eliminating the uncertainty that today attends the daily reception, over long distances, of educational and entertaining programs.

Direct-current Reactor Design

By D. C. Prince

Research Laboratory, General Electric Company

The author discusses the design of direct current, or smoothing, inductances in a comprehensive but very simple manner. The use of such devices in a rectifier circuit reduces to a very considerable extent the current variations.—Editor.

Many persons are now using smoothing inductances in connection with thermionic rectifiers for supplying direct current to radio sets. The purpose of these inductances is to reduce the current variations which naturally occur in the output of a rectifier and which introduce noises which interfere with signal quality. The reason for the pulsations is the variation in the rectified voltage. Referring to Fig. 1, the primary *T* of the transformer *TT′* is connected to a source of alternating current. The ends of the secondary winding are connected to the plates or anodes of two rectifier tubes *a* and *a′*. The cathodes or filaments *c* and *c′* are connected together and the load resistance *R* is connected between the neutral of transformer secondary winding *T′* and the common filament connection. Voltage and current relations are shown in Fig. 2. When the potential e_a of the anode *a* is positive with respect to the cathode, current flows from *T′* through *a* to *c* and through the load *R* back to the neutral of *T′* as shown by the arrows. Current cannot flow from the cathode to an anode through a rectifier, so none flows in the circuit of *a′ c′* during this time. When the alternating voltage goes through zero the current decreases and would cease entirely except for the leakage reactance of the transformer. Then, when anode *a′* becomes positive, it flows in the circuit *a′ c′* returning through *R* as before. The current then tends to pulsate as shown in *i* of Fig. 2.

An inductance *L*, Fig. 1, tends to reduce the pulsation of current. It acts like mechanical inertia offering no resistance to a steady flow but opposing all changes. The smoothing effect is proportional to the inductance which is measured in henries. The inductance must carry the current required for any particular application. These two factors determine the size of the device. There are available formulas* by which the inductance of an air cored coil may be calculated. However, the introduction of iron into the magnetic circuit greatly increases the inductance. An interesting thing about this increase is that where direct current must be carried the greatest useful inductance is obtained when the magnetic circuit is not all iron but contains an air gap.

To explain this phenomenon, Fig. 3 has been prepared. A certain iron core wound with a coil has a magnetization curve *1*, Fig. 3. If an air gap is cut in the iron the reluctance is increased and the magnetization curve is *2*, Fig. 3. A still larger air gap gives the curve *3*, Fig. 3. When the current pulsates the flux changes and in so doing induces a voltage in the coil which opposes the pulsation. The voltage is produced only by a change of flux so that the steepness of the curve is the measure of the voltage tending to reduce pulsation rather than the value of the total flux. Thus, if current pulsates between 0.5 and 1 amperes and there is no air gap, the induced voltage is proportional to 7 kilolines. But if the current pulsates between 2 and 2.5 amperes, the induced voltage corresponds to less than 2 kilolines. By inserting the air gap corresponding to curve *2*, a current pulsation from 2 to 2.5 amperes causes a flux variation of about 15 kilolines so that the voltage tending to oppose the pulsation is

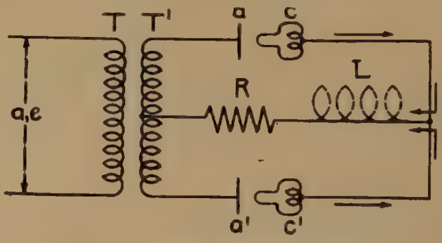

Fig. 1. Simple Rectifier Circuit

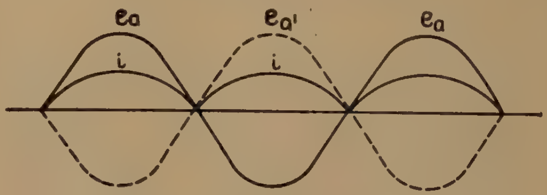

Fig. 2. Rectifier Wave Forms

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*Bulletin of the Bureau of Standards, Vol. 8, No. 1.
Univ. Illinois Bulletin No. 53.

greatly increased. Similarly with a current pulsating between 5 and 6 amperes, the still larger gap represented by curve *3* gives the best results.

If there were no hysteresis the curves of Fig. 3 could be produced accurately and used to design inductances. But on account of hysteresis a small current variation never produces as much flux variation as the steepness of the magnetization curve would lead one to expect. Instead, the small variations in current carry the flux through such small loops as those shown in Fig. 4, the effective slope of which is much less than that of the magnetization curve. Larger and larger current changes give flux changes nearer to those given by the slope of the magnetization curve. For very small current changes the effective slope approaches zero.

The problem before the designer of an inductance intended to carry direct current is to put all these variables into such form that he can tell, by a small amount of calculation, what may be expected of any given arrangement of coil and iron and where to look for the best combination in any given case.

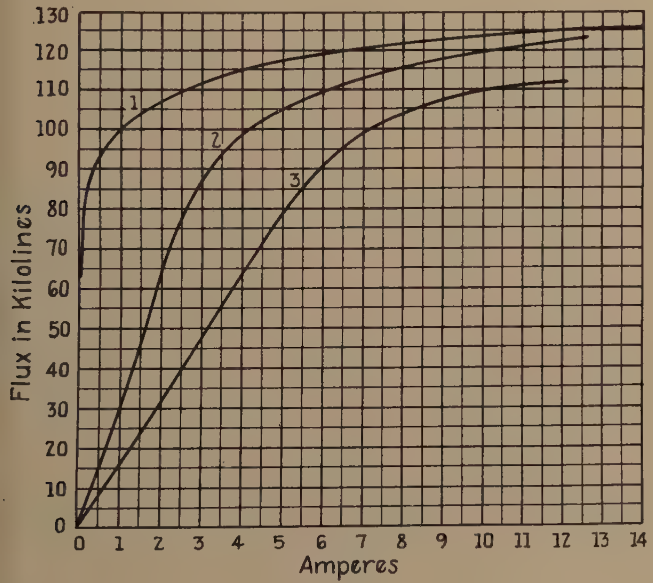

Fig. 3. Reactor Saturation Curves

Suppose as a first approximation that hysteresis may be neglected. We then have a reactor that corresponds to curve *1*, Fig. 3. This reactor is to be used in series with a rectifier and the direct current at which it works best is to be determined. By "working best" we mean reducing the current pulsations to the least fraction of the whole current. The rectifier has an average direct voltage of 100 and a superimposed voltage of say 10 volts in pulsations at 120 cycles. The reactor has an inductance.

$$L = NS\times 10^{-5} \text{ henries where}$$

L is inductance in henries, N the number of turns in the coil, say 1000, and S the slope of the magnetization curve, Fig. 3, in kilolines per ampere.

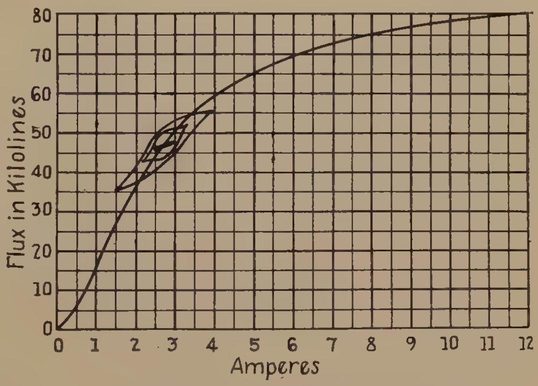

Fig. 4. Hysteresis Loops for Small Current Variations

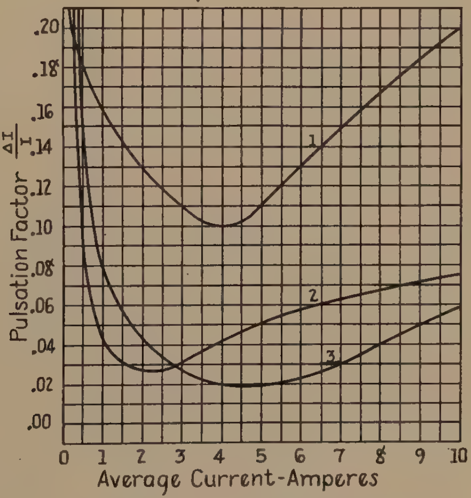

Fig. 5. Effect of Air Gap and Average Current on Pulsation Factor, Neglecting Hysteresis

The ohmic inductance is

$$X = 2\pi fL$$

The pulsating component of current is

$$\Delta I_r = \frac{\Delta E_r}{X}$$

If now we plot the values of

$$\Delta I_x/I$$

for various values of direct current I, we get the curve *1*, Fig. 5. The pulsation ratio goes through a minimum at 4 amperes and then rises again. If it were desired to operate at 2 amperes, the number of turns should be doubled. The minimum pulsation would then occur at 2 amperes. If the reactor were to be used at 8 amperes, the number of turns should be halved. The minimum pulsation would then occur at 8 amperes. By cutting an air gap in the reactor it may be made to conform to curve *2*, Fig. 5. It now gives a lower minimum pulsation at 2 amperes and, as before, the minimum can be shifted back and forth by changing the number of turns. As we go in the direction of larger and larger air gap, we apparently get greater and greater efficiency in the reactor, but a little consideration will show that we are adding copper with each increase in air gap. The reactor of curve *2* had very little copper because it was most effective at a small current. The reactor of curve *3* must have a larger amount of copper if advantage is to be taken of the increased current at which the pulsation is a minimum.

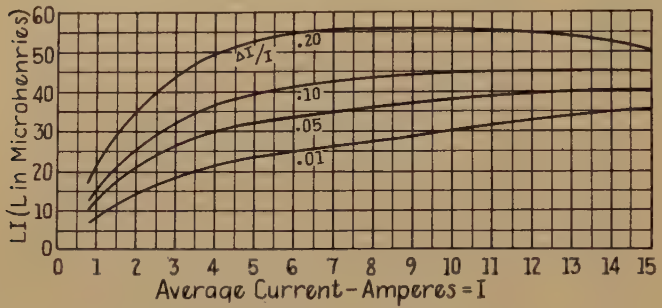

Fig. 6. Effect of Pulsation Factor and Average Current on *LI* Product of Unit Reactor (1 Inch Cube) with 1 Turn, Zero Air Gap, and Hysteresis Considered

The designer must choose an air gap which will give him the best balance of copper and iron and then work the iron at the point of least pulsation factor.

Suppose now the reactor of Fig. 3 to have its cross section doubled. The total flux and flux change will both be doubled and the number of henries will be doubled. If instead of doubling the cross section we double the length, simultaneously doubling the number of turns, this will leave the flux unchanged, but a given flux change will cut twice as many turns and induce twice as many volts, so that the henries will be doubled. Neither of these changes will alter the iron density at which the best pulsation factor is secured. The inductance is thus directly proportional to volume if turns per unit length are kept constant. In reducing reactors in general to a common denominator, it is possible to assume a unit reactor of unit cross section unit length of magnetic path and n turns, from which other reactors may be built up by taking any number of unit reactors and adding them together, keeping constant turns per unit length of magnetic path.

In the study of unit reactors the approximation of no hysteresis need not be made. Fig. 6 is derived from tests of actual iron samples reduced to the dimensions of a unit reactor having no air gap and one turn.

The ordinate LI is proportional to the reciprocal of the ordinates in Fig. 5, by the following reasoning:

$$\frac{\Delta I}{I}=\frac{\Delta E}{IX}=\frac{\Delta E}{2\pi fLI} \text{ so that}$$

LI is inversely proportional to $\dfrac{\Delta I}{I}$

By calculation a new set of curves similar to those in Fig. 6 can be derived taking into account the effect of an air gap. The assumption must be made that the air gap reluctance may be added to the equivalent reluctance of the iron for small changes in magnetization, but this assumption has been justified by careful test. Fig. 7 is equivalent to Fig. 6 except that an air gap has been inserted equal to 2 per cent of the total magnetic path. It will be noticed that these curves peak sharply at $I = 475$ amperes. By choosing the

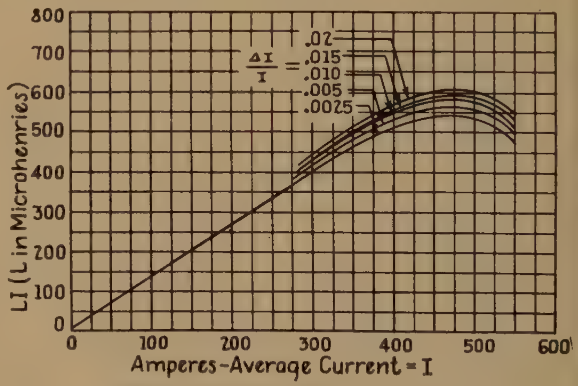

Fig. 7. Effect of Pulsation Factor and Average Current on *LI* Product of Unit Reactor (1 Inch Cube) with 1 Turn, Air Gap 0.02, and Hysteresis Considered

peaks in Fig. 7 and similar curves for other air gaps, a set of curves such as shown in Fig. 8 can be derived.

Fig. 8 gives the number of ampere-turns for a unit reactor to work it at the point of least pulsation, this minimum pulsation being marked on the curves. The corresponding inductance of the unit reactor is also given as a function of the air gap.

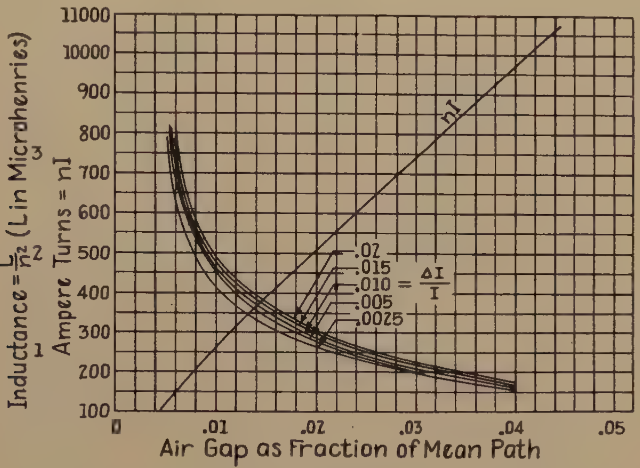

Fig. 8. Effect of Air Gap on Inductance of Unit Reactor (1 Inch Cube) with n_1 Turns Per Inch; and Effect on Ampere-Turns for Least Pulsation Factor

A reactor of any size can be built up from the unit reactor data. An example will illustrate this. Suppose a reactor is desired which will have an inductance of 2 henries when carrying 5 amperes direct current and 0.02 pulsations. It should be laid out for several air gaps to find which is best.

(1) Air gap	0.01	0.02	0.04
(2) nI from Fig. 8	260	500	970 ampere-turns
(3) $L/_{n^2}$ from Fig. 8	2	1.2	0.7×10^{-6}
(4) $n = (2) \div (5)$	52	100	194
(5) $L = (3) \times (4)^2$	5.4	12	26.3×10^{-3} henries

(5) is inductance of unit reactor.

(6) $V = 2 \div (5)$	370	167	76 cu. in.

(6) is the number of unit reactors required and gives the total volume of iron. The number of turns n is not changed so that the total turns will depend on the form finally chosen for the core iron.

A designer with a book of standard cores looks until he finds which one gives the best ratio of iron to copper and selects that one.

In order to keep the flux from setting up losses in neighboring structures, it is desirable to split the air gap into several parts and to keep these parts inside the coils. If this is not done, the measured air gap and the effective air gap do not correspond, since the area of the actual gap is greater than the iron section. The effective gap is then less than the measured gap, and an allowance must be made therefor.

This method is not only useful in giving the apparatus designer means for laying out direct-current reactors; it also furnishes the iron specialist with a measure for comparing samples of reactor iron in a way to give most assistance to the designing engineer.

Tendencies in the Electrification of Cuban Sugar Mills

By C. A. Kelsey

Industrial Engineering Department, General Electric Company

Cuba offers a striking example of rapid progress in the adoption of electric drive to its principal industry where the generation of power is in the nature of a by-product and efficiency of power application is not a deciding factor. Electric drive has proved to be more reliable and to cost less for maintenance than steam engines and steam pumps. This transformation has taken place since the year 1912; and while the output of the mills has meantime increased from two and a half to four million tons, electric drive now accounts for over sixty per cent of the total. This article discusses the engineering features in the development of electric drive.—Author.

The electrification of Cuban sugar mills has now reached a high state of development. The adoption of electric drive, as in any other industry, was attended with subsequent improvements in the manner of power application and the selection of features particularly suited to the condition of operation. Experience is always helpful in improving on human forethought. By closely following the operation of electrical apparatus, through observation and discussions with operators, engineers have been able to acquire the knowledge necessary to perfect the application of electricity to the peculiarities of the service requirements.

The apparatus furnished at first was, in general, of the manufacturer's standards modified only in certain respects to meet the special requirements then apparent. Simplicity in design and ruggedness of construction were sought to insure successful operation in the hands of operators unskilled in the use of electrical equipments. A liberal factor of safety was included in the selection of the motor ratings.

As time went on and experience was gained, refinements were made in the selection of motors and control equipment to make them more closely fit the loads of the various machines and the conditions of service. Direct-current power was first used because of the prevalence of this form of electric power for the lighting systems. The three-phase, 60-cycle, 440-volt, alternating-current system was later found to be more suitable.

The first requisite is reliability. The mill must be able to operate continuously without any enforced shutdowns due to the failure of the power system. Electric drive has fully established the reputation of being the most reliable system of power application. Interruptions due to failures of electrical apparatus were at first considered as likely to occur, the same as with steam-driven machinery, but as means were found to avoid such failures the service demanded of electrical equipment is now almost perfect. Records from a large number of mills show that the time lost in grinding chargeable to electric drive is negligible and many mills report no lost time for an entire season.

The use of spare power units, pumping equipments, and motors for mechanical drives further minimizes the possibility of power interruptions. The spare units can readily be put into operation without interrupting service.

The next requisite in point of importance is economy. This factor should be considered broadly. Cost of operation and general fitness should govern, rather than the efficiency, from a purely power standpoint. The cost of power in a sugar mill is very low and an inefficient form of drive may yield a minimum of operating cost and a maximum of service. As an example, it is better to use a large squirrel-cage motor to start a conveyor than a smaller slip-ring motor, which is closely fitted to the normal load when up to speed. The squirrel-cage motor will have a lower efficiency than the slip-ring motor at the full load of the latter, but the total cost of operation will be less.

Considering the power generating equipment, the non-condensing turbine-generator is the accepted standard. The impulse type, consisting of a single wheel with a double row of buckets, predominates. The turbine blading is made of non-corrodible metal to withstand better the effects of moist steam and sugar vapor. The emergency shut-off throttle valve must be free from sticking caused by the small amount of sugar coming over with the steam. The gumming of the pilot valve for the load governing valves has been eliminated by substituting oil, from the pressure lubricating system, for the steam.

The practice now is to omit the exciter from the turbine and provide excitation from motor-driven exciters. A steam-driven exciter is then required for starting up the plant. This simplifies the design of the turbine, and where two or more generators are operated in parallel, a single exciter can be used.

The 1000-kw. size is the most popular in point of number for the main power units. Usually two such units are installed for spare capacity. Smaller capacity units are much used for carrying the load during liquidation or shut-down periods. In recent years some larger mills have purchased 2000-kw. units so that all of the load can be carried by a single generator but this practice is not general. A number of units provide greater flexibility and no trouble is experienced with parallel operation.

The use of vapor heating and other means for better economy in the use of exhaust steam have created a demand for prime movers with lower steam consumption. This condition has been met by the use of higher boiler pressures and super-heated steam. The larger capacity single unit turbines were installed partly because of better steam economy. The Corliss engine is again being considered because of its better economy. The engine-driven unit is, however, higher in first cost and maintenance expense, and is still objectionable because of the cylinder lubricating oil which is carried into the heaters and evaporators. The solution of the problem can better be made by the use of superheated steam and the improvement in the turbine.

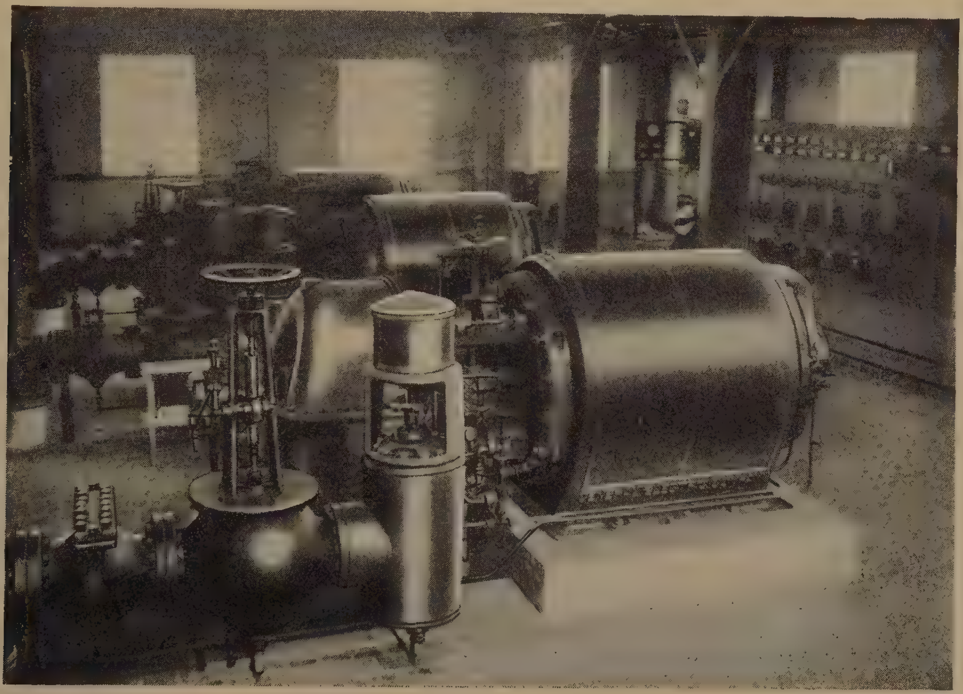

Fig. 1. Power Plant in a Modern Sugar Mill, Central Boston

The switchboards now being furnished are a great advance over those at first installed. The earlier boards were of the simplest design possible to control the generators, exciters, and outgoing feeders. They are now properly considered as being a very important link in the power system. The board for the dead-season power plant is now separate from the main operating board. The dead-season board controls the small generator, the lighting, and those motors which are not used directly in the manufacturing processes. A tie-in connection makes possible the use of power from either the main power or dead-season generators. This scheme permits the removal of power from the main board for repairs or adjustments without danger to the workmen.

The main switchboard is now provided with features which insure against shut-downs from possible failure of switchboard equipment. All high-voltage power circuits have been removed from the front of the board and fused switches replaced by oil circuit breakers. In the larger plant, the oil circuit breakers are located in a basement directly underneath the panels. Disconnecting switches between the breakers and the power bus make possible the isolation of any breaker for repairs. These features all tend to greater safety to the power plant attendants. An extension of the idea of greater safety and reliability is in the use of sectionalized buses and auxiliary buses. The auxiliary bus with double-blade double-throw switches permits the isolation of any feeder breaker without interrupting the feeder circuit. This auxiliary bus extends back of the feeders and is connected to the main power bus by a tie breaker. Normal operation is from the main bus through the feeder breaker to the feeder cable. The feeder can be transferred to the auxiliary bus by throwing one blade of each phase, at a time, to this bus. This action does not interrupt the power flow. The feeder thus transferred is still protected from overload by the overload trips of the tie breaker.

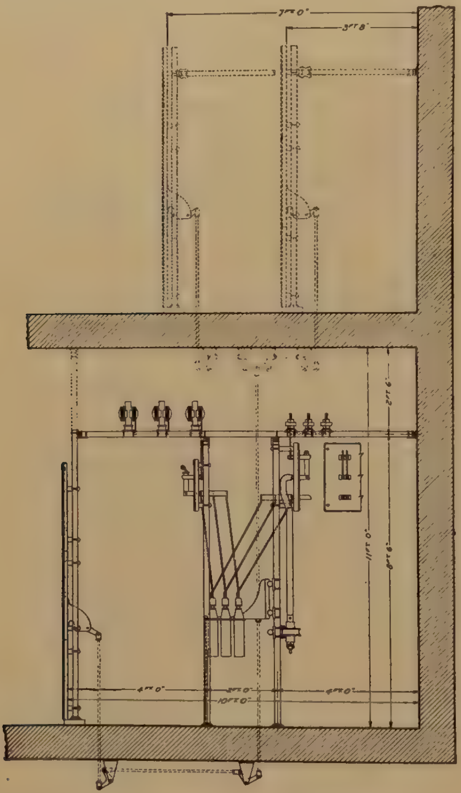

Fig. 2. Auxiliary Bus Arrangement

Automatic generator voltage regulators are now freely used. It has been found that the voltage regulation is far better than that resulting from hand control by the switchboard attendant. The lighting of the mill by high efficiency incandescent lamps from transformers fed from the power bus requires a steady voltage to give long life to the lamps.

The equipment on the switchboard panels has been augmented by integrating and curve drawing watthour meters, instrument testing receptacles, and temperature indicating equipment. The temperature indicating equipment is connected to resistance coils embedded in the generator windings. A direct reading of the generator temperature is given on an instrument. The maximum permissible load can thus be carried on the generators without fear of overheating.

In following the flow of power, we next come to the distribution system. Many methods of carrying the feeder cables from the main switchboard to the motors have been employed with varying success. Cables have been run in underground metal or fibre conduit and on insulators overhead. Lead-covered underground cables have also been used. All of these systems have eventually resulted in cable failures and consequent shut-downs. It is difficult to keep moisture out of underground conduits, unprotected cables overhead become grounded by contact with piping and metal parts of the building, while the lead-covered cables were not properly sealed at the ends and at joints and were damaged by workmen digging for new pipe lines or foundations. Many mills have now changed to overhead metal conduit. In the case of large mills recently erected, the cables have been run with success on insulators in a well drained tunnel.

The practice is now to run a feeder circuit to a distribution panel located near the center of a group of motors which it serves. These panels are enclosed with a grille and protected by a metal roof. Fused switches for the individual motors protect the motor feeder cables and provide a cutout for removing power from the motor and its control equipment. A similar design of panel is used with large motors for driving injection water and vacuum pumps. The controller and starting resistors are mounted integral with the panel and its enclosing framework.

We now come to the application and control of power to the apparatus and machinery used in the manufacturing processes. Aside from the driving of the crushing rolls and centrifugal extractors, no unusual problems are encountered. Standard industrial types of induction motors with moisture-resisting insulation have given satisfaction. The tendency is to use the squirrel-cage motor wherever possible. The centrifugal pumps are driven by high-speed motors but the conveyors require low-speed motors with some form of speed reducing motion. Back-geared attachments furnished by the motor manufacturer have been extensively employed although some contractors favor the high speed silent chain drive. The latter costs more, but is quieter and requires less skill in lining up. The motor with chain drive must be located close to the driven shaft, whereas a back-geared motor can be located on the floor and a roller type chain run between the back shaft and the driven shaft overhead.

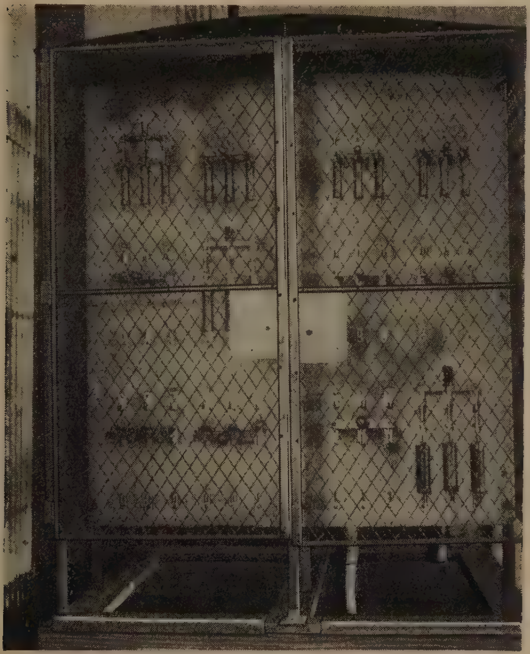

Fig. 3. Distribution Panel

The control equipment must be as simple as possible, and yet properly control and protect the motor. Fuses were at first used to protect the motor from overload but the delays in renewing with proper size fuses led to the use of overload relays. To simplify further the starting of the squirrel-cage motors up to 15 h.p., oil circuit breakers are replacing starting compensators. The operator simply closes the breaker instead of the two movements required by the starting compensator. For the variable-speed operation of the cane elevators and conveyors, drum controllers which handle both the primary and secondary circuits of slip-ring motors have proved more satisfactory than contactor panels. Over-capacity controllers are used to minimize the wear and arcing from the frequent operation of the variable-speed motors required for this service. The preference for drum controllers over contactor panels is due to the facility of locating the defective contacts and quickly making adjustments. Faults in a contactor panel are likely to occur in the dusty atmosphere prevailing and are not so readily located.

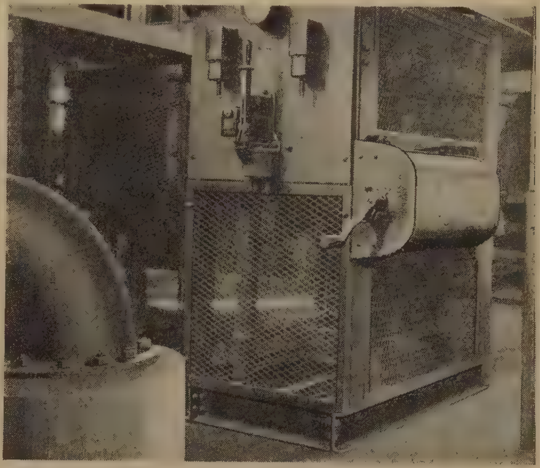

Fig. 4. Individual Motor Panel

Automatic control of pump motors is used for service water supply and to a limited extent for juice pumping. This type of control is of benefit only where there is a possible reduction in the number of attendants. It can be used to advantage in limiting the pressure on filter presses where plunger pumps are employed. Float switches are used with overhead syrup storage tanks to avoid overflowing.

The application of motor drive for the grinding rolls has been slow. The driving of the rolls by motors was started in the year 1914. Resistance speed control was used to obtain the reduced grinding rate. This method of control does not give stable operation at reduced speeds, which defect was attributed to the coarse speed adjustments from the small number of operating points. An attempt was made to correct it by employing water rheostats, but this did not remove the inherent instability and moreover the water rheostats were troublesome. A number of this type of drive were installed until the year 1918, when a new system was inaugurated at Central Cunagua.

The new system of cane roll drive, known as the Variable-frequency System, employs a variable-speed turbine to drive a separate generator for the roll motors. The relative speed adjustments between mills is limited to 10 per cent, which is within the limit of stable operation. The variation in the grinding rate is accomplished wholly by control of the generator speed. The few resistors required for starting and relative speed adjustments and the control panels are placed in a chamber underneath the motor platform, and thus do not require any additional floor space. This system has solved the problem of roll drive and recent installations have been of this type. The engineers and superintendents are gradually learning of the simplicity of operation and the benefits accruing from this improved system, and thus interest in the motor drive of rolls has been revived.

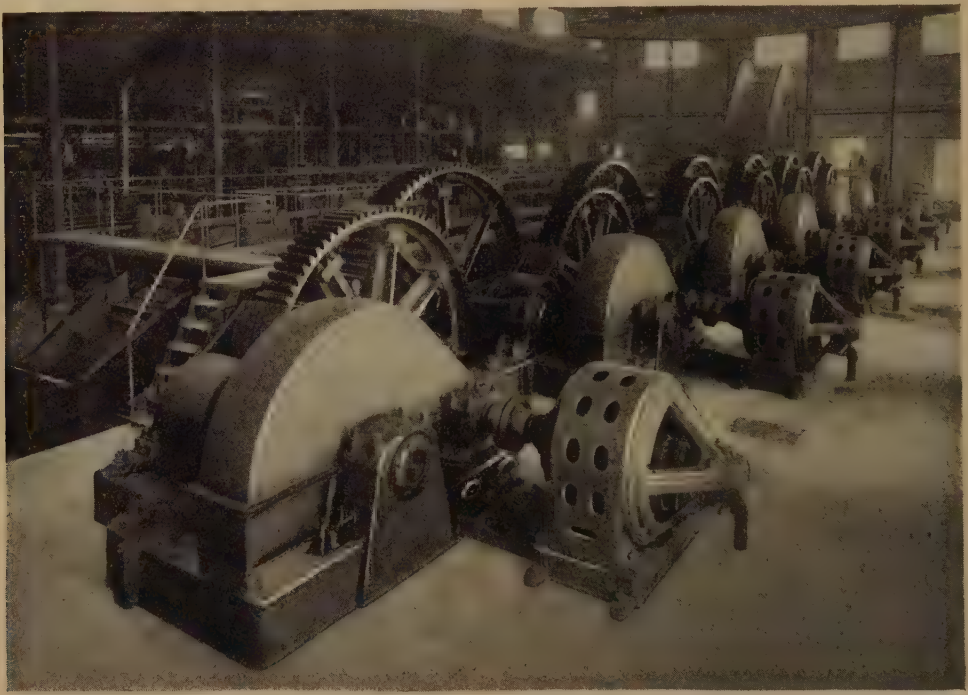

Fig. 5. Motor-driven Rolls, Central Cespedes

Recent developments in motor applications to centrifugal extractors have brought the individually motor-driven centrifugal into prominence. The shorter cycle of operation possible with the individually motor-driven machine and the almost complete elimination of the maintenance expense has a strong appeal to the management.

In tracing the history of motor-driven centrifugals, it is found that the squirrel-cage induction motor with a slipping centrifugal type clutch was first used. The rapid wear of the clutch was objectionable, however. Direct-coupled slip-ring motors were then introduced. The resistance and slip rings were objectionable from the standpoint of space required and brush maintenance. Squirrel-cage motors for direct coupling without clutches were then installed, but they do not provide low speed for discharging except by the use of a low-frequency source of power for this purpose.

The recent adoption of a multispeed squirrel-cage motor with an improved clutch appears to offer a satisfactory means of meeting the requirements of an economical drive, which will be universally suited to drying both high- and low-grade sugars and to provide for power discharging. The variations in the motor speed can be effected either by polar groupings of the field winding or the use of variable voltage impressed on a single winding. The reduced speeds of the motor cause the centrifugal clutch to exert reduced torques and hence slower acceleration of the centrifugal. Lower torque values are thus available for power discharging. The two-speed motor limits the operation at two values of torque but by providing a number of taps on the auto transformer with the variable voltage motor, any desired value of torque can be obtained.

The inexpensive high-speed motor-driven vacuum pump has supplanted the large and expensive low-speed steam-driven pump. A high-speed motor is belted to the flywheel of the pump with an idler pulley to permit a short belt. This makes a compact unit. A further improvement can be made by using a synchronous motor mounted on the crank shaft.

Electricity is used for lighting in all of the mills. The large amount of electric power available in those mills electrically driven has elevated the standards of illumination so that operation is equally efficient day and night. The incandescent lamp is universally used. Large capacity units up to 1000 watts illuminate the high interiors and smaller units furnish high-intensive lighting. Floodlights are much used around the cane unloading stations and car tracks.

The economical production of power and lighting for the dead season has been a difficult problem. Many mills supply electricity for lighting nearby towns and service must be maintained during the dead season. Power can be generated economically during the grinding season from the main non-condensing power units but purchased fuel is required during the dead season. Some other type of generating unit is therefore required to give cheap power for this small load.

Small non-condensing steam turbines when exhausting to atmosphere have a high steam consumption, but by operating condensing the over-all economy is acceptable. Crude oil engines have been tried but the low-grade oils were found to give trouble, and thus the oil ordinarily burned under the boilers of the steam plant must be replaced by more expensive fuel. The maintenance of the crude oil engine was found to be high, so that no material gain was made. The uniflow type of engine has been used with considerable success, but here again the maintenance is high. The central station system with transmission lines extended to reach the surrounding mills is now being inaugurated and is meeting the situation. The use of central station power eliminates the dead season or auxiliary power plant and the attendants at the mill, and on this basis can successfully compete with the small inefficient plant at the mill.

Cuba is thus well on the way towards realizing all the benefits of electric drive, the same as in the United States where electric power has been carried to the highest plane of economy and service.

Mechanical Features of the Gearless Traction Elevator Motor and Brake

By J. J. Matson

Industrial Department, General Electric Company

In our August, 1923, issue we ran an article on "The Probable Number of Stops Made by an Elevator," and in the February, 1924, issue an article on "The Time-velocity Characteristics of the High-speed Passenger Elevator." These presented a theoretical treatment of elevator service. In the following article a description is given of the mechanical features of the gearless traction type of elevator machine. It shows how the manufacturer's engineers have made a thorough study of each part and have developed a most capable elevator hoist.—Editor.

The constant increase in land values necessitates increased heights of buildings in order that they may be a paying investment. In general, the higher the building the higher the required elevator speed, thus the percentage of high-speed elevators has rapidly increased to keep pace with modern building construction. The operation of elevators running at 500 ft. per min. or more is improved by eliminating gear reductions between the motor and driving sheave, and for some years gearless elevator machines have been standard for these high speeds. A gearless machine, as shown in Fig. 1, consists of a low-speed direct-current motor having the rope sheave and brake wheel mounted on the motor shaft, the brake mechanism being conveniently mounted on the bearing cap to form a complete self-contained unit.

In designing elevator equipment, safety must be considered as the most important factor although other things such as reliability, appearance, minimum floor space occupied, etc., must also be considered. In order to check the design data complete tests should be made on the various composite parts as well as on the completed machine.

The various mechanical features which have been most carefully considered in the design of the motor are:

(1) Shaft
(2) Method of lubrication
(3) Compactness
(4) Bearings
(5) Sheave and brake wheel
(6) Rope guard
(7) Brake construction and mounting

One source of trouble with gearless elevator machines is a slight loosening of the armature spider on the shaft, usually causing a very annoying creaking noise during operation. The cause has been traced to the fact that the shaft diameter where the spider is keyed on is relatively small and permits sufficient deflection to wear the keys thereby allowing the spider to become loose. To overcome this difficulty a one-piece shaft and spider was designed (see Fig. 2). The part to which the armature punchings are keyed is of large diameter thus eliminating deflections to such an extent as to avoid all creaking noises. In order to keep the weight of the rotating parts at a minimum and reduce accelerating losses, a hollow construction was adopted.

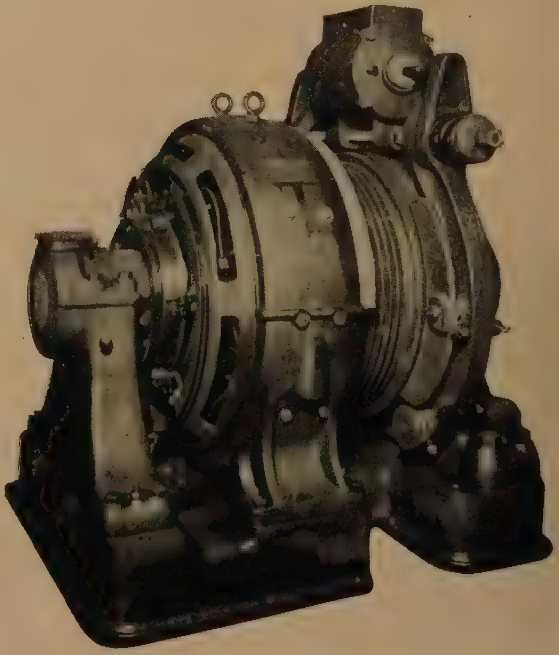

Fig. 1. Gearless Traction Elevator Motor with Rope Sheave and Solenoid Brake

As the strength of this one-piece shaft and spider is of utmost importance, the details of its construction have received most careful attention. It is a casting of the highest grade electric furnace steel and a special heat treatment is applied to the rough casting in order to obtain the proper physical properties.

To check the design and insure ample strength a completed shaft on which was assembled a standard rope sheave and brake wheel was mounted in its own bearings and coupled to a driving motor for complete tests (see Fig. 3). A long I-beam was pivoted near the member under test, and a block and chain were used for loading. A calibrated spring balance between the chain block and the I-beam accurately measured the load applied to the shaft. The load was applied to the shaft through a brake shoe bearing on the sheave surface, the grooves having been machined off in order to give a suitable bearing surface. The brake shoe was water cooled so that the loads could be increased as much as possible. Loads up to four times normal were applied to the rotating drum for extended periods of time and the various effects noted. The tests proved conclusively that the shaft was well designed.

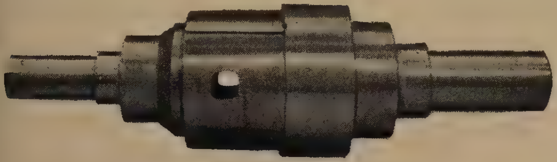

Fig. 2. Shaft for Gearless Traction Elevator Motor

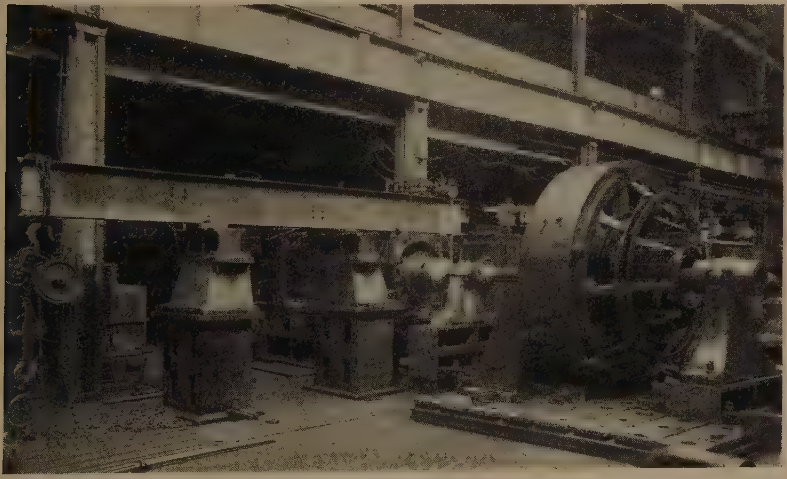

Fig. 3. Loading Tests on Shaft and Bearings for Gearless Traction Elevator Motor

To insure that subsequent shaft castings come up to the adopted standard, all castings are somewhat longer than required thus permitting a test coupon to be cut from each. This coupon is carefully tested before any machine work is done and unless the tests are satisfactory the rough casting is scrapped.

In the past the motor bearings have been lubricated either by oil rings or chains, the rotation of the shaft rotating the rings or chains, which carry oil to the bearing surface. Either of these methods has three main faults.

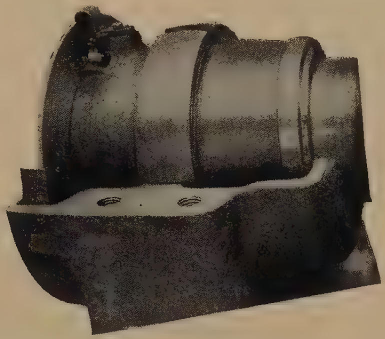

Fig. 4. Bearing for Gearless Traction Elevator Motor with Cap Removed to Show Lubrication Device

(1) The bearing surface must be broken to allow the chains or rings to rotate freely.

(2) Due to the low motor speed there is a tendency for the rings or chains to slip and even stop. This materially reduces the amount of oil supplied to the bearings.

(3) It is necessary to have the motor make approximately one half revolution before oil is delivered to the bearings.

To overcome these troubles experienced with oil rings or chains, a positive oiling device was needed. This was obtained by attaching a solid disk to each end of the motor shaft, the lower part of the disk dipping in the oil bath (see Fig. 4). An oil deflector bears against the disk and removes the oil carried up. It is then led to a reservoir in the top of the bearing from which it flows by gravity to the journal surfaces. The reservoir will not drain during the ordinary stops in service operation and thus oil is supplied to the bearings as soon as the motor starts. This method is proving very satisfactory.

The bearings are all of the spherical seat type. This is a very desirable feature as all buildings settle and might cause a motor equipped with ordinary bearings to get out of alignment. The result is a longer bearing life and lower friction loss.

Floor space is valuable and thus all elevator equipment must be as compact as is consistent with good design. Some of the methods used to obtain this compactness are:

(1) A unit casting for rope sheave and brake wheel.
(2) Armature windings extend a short distance beneath the rope sheave.
(3) The bearing extends inside the commutator shell.

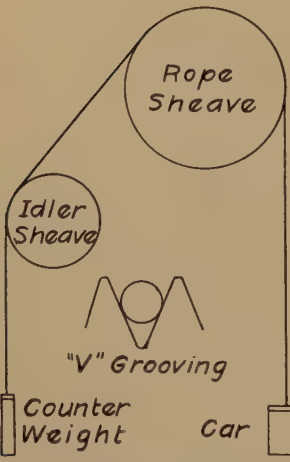

Fig. 5. Diagram of Half-wrap Traction Roping

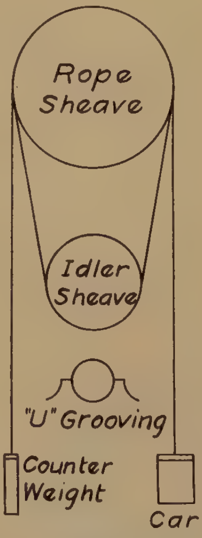

Fig. 6. Diagram of Full-wrap Traction Roping

The sheave and brake wheel were carefully considered both as to proper material and method of construction. Semi-steel was found to be the best material since it is as hard as can be conveniently machined and also gives good wear. All sheaves before being machined are tested for hardness. Only such as come up to the standard are finished.

In assembling the machine the sheave and brake wheel are pressed on the shaft under hydraulic pressure. Care is taken to use pressures which will not stress the hub beyond the elastic limit. The pressures used are sufficient, however, to prevent the sheave slipping when maximum load is being handled even if no other method of securing was used as an additional factor of safety. Six bolts are used to fasten the sheave member to the shaft and two substantial dowel pins are driven in holes drilled exactly on the contact line between the sheave and the shaft. The combination of the three methods of driving insures a tight assembly and eliminates the possibility of the sheave becoming loose.

Either of two shapes of grooves are used on these machines, the one being known as the V-groove construction and the other as the U-groove construction. The names are derived from the shape of the grooves. With V-grooves the ropes make approximately 180 deg. contact with the sheave, the ropes coming from the car passing over the sheave and going to the counterweight. Traction is obtained from the wedging of the cables in the grooves. This system is also called "Half-wrap traction" (see Fig. 5). The idler sheave is used only when the distance from the center of the car to the center of the counterweight is greater than the diameter of the rope sheave. With U-grooves the ropes make approximately 360 deg. contact with the sheave, the ropes coming from the car passing over the sheave, then over an idler sheave back over the rope sheave and then going to the counterweight. This type of roping is also known as "Full-wrap traction" (see Fig. 6). The rope sheave is machined to permit six ⅝-in. cables being used with either type of grooving. This requires six V-grooves or twelve U-grooves.

A careful study of the two methods of grooving has been made and the General Electric Company has decided to standardize on U-grooves. The reasons for this decision are:

(1) Past experience of large manufacturers of gearless machines indicates that U-grooves are most satisfactory for high-speed elevators.
(2) Noise has been experienced with V-grooves due to the ropes leaving the sheaves.
(3) The U-groove, being circular, is the same for any given rope diameter; whereas there is no universal standard shape of V-groove. Thus much better manufacturing and stocking conditions may be obtained when U-grooves are used.

The brake wheel is 40 in. in diameter while the sheave diameter varies with the car speed, being 36 in. for 600 ft. per min. The brake wheel is always larger in diameter than the rope sheave as with this construction the brake mechanism is protected against fouling should a rope jump out of the groove.

As the rope sheave extends over the end of the armature coils, the end rope jumping from its groove might damage the windings. In order to protect against such trouble a guard is attached to the motor frame and is so placed that a rope out of its groove cannot damage the armature windings.

When regarded from the standpoint of safety, the most important part of the gearless machine is the solenoid brake for it is used partially for stopping the elevator and entirely for maintaining it stationary at the floors. Should the brake for any reason fail a serious accident might result, and to reduce the possibility of the brake failing very careful consideration was given to its design. The brake is spring set and the mechanism is such that each shoe is independent of the other so that if for any reason one half of the brake becomes disabled the other half will operate giving one half of the total retarding torque. The brake shoes each make contact with about one-quarter of the brake wheel and are six inches wide. The contact surface is approximately 375 sq. in. which results in a relatively low unit pressure, thus increasing the life of the lining. The brake lining is of an asbestos compound and does not have interwoven metallic wires. Wires are undesirable for in time the lining wears down to the point where the wires come in contact with the brake wheel surface and result in a harsh application of the brake and a scoring of the brake wheel.

The solenoid for operating the brake is mounted on top of the sheave-end bearing pedestal. It is designed for a wide variation in torque thereby permitting adjustments to be made so that the brake, which is really a service brake, can also be safely used when overloads such as safes are being handled. It is important to have some means of resetting the brake for service operation when finished with the handling of safes, and the simplest way of duplicating adjustments of torque is by duplicating the compression of the springs. Mounted on the brake is an indicator which shows the length of the springs, which is a measure of torque in foot-pounds. A quick approximation of service settings can be obtained after the safe handling operations are completed by the use of this indicator. The solenoid has two moving cores with push rods from each passing through the other core which construction eliminates the extra pivot point used on many similar brakes. These extra pivot points are otherwise required due to pull rods being attached to the solenoid cores instead of push rods. The brake posts are pivoted at the bottom, being supported from the bosses at the base of the bearing pedestal. The shoes are supported at their mid-point by the brake posts and are self-aligning. Provisions are made for adjustments so that substantially the same gap at all parts of the shoe is obtained when the brake is released. The movement of brake shoes is kept at a minimum so that jar due to the inertia of all moving parts of the brake is eliminated.

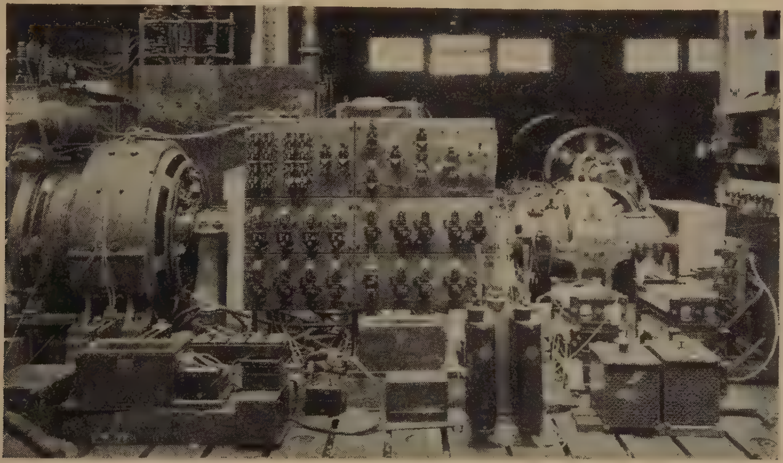

Fig. 7. Gearless Traction Elevator Motor and Control Arranged for Elevator Loading Tests

The motor used in this gearless traction machine is equipped with commutating poles which give good commutation under all conditions of load. This is a departure from other machines but a close study of characteristics proves the wisdom of this feature in the design.

Tests of the completed installations show the speed regulation between full load *up* and full load *down* is very close. This is important as it makes unnecessary the use of speed regulating contacts on the governor switch.

A test tower was not available for making tests on a gearless machine together with its control and as such tests were necessary a means of obtaining them had to be devised. The method selected required the motor having a shaft extension for gearing it to a series-wound load generator which has a moment of inertia (when reduced to the elevator motor shaft) practically equal to the effective inertia of the moving parts of an elevator (see Fig. 7). The generator was a 230-volt machine and was connected in series with a water rheostat across a 500-volt power supply. By varying the water rheostat setting any load can be obtained, which load remains substantially constant regardless of the speed of the generator. A motor load is obtained when the elevator motor revolves in one direction and a regenerative load is obtained when the rotation is in the opposite direction. If loads corresponding to the elevator loads are selected very good results can be obtained as both the inertia and the dead loads of the elevator can be closely approximated. This method of testing has one big advantage over a test shaft in as much as unlimited runs can be obtained. It has been found that results and adjustments obtained from such a test compare very closely with those required for an actual installation.

Automatic Station Equipment for Industrial and Power Systems

By Chester Lichtenberg

Switchboard Department, General Electric Company

Automatic station equipment in the service of railways and central station systems has already proved itself to be thoroughly practical and reliable. (These are characteristics of primary importance, for without them the equipment would not be open to consideration at all.) The real appeal of automatic equipment, however, lies in its decided superiority with respect to the quality of service and economy of operation it effects. Because the art of automatic control is advancing rapidly, and is being extended to cover widening fields of operation, this article was written to furnish a comprehensive view of its various applications. It is an expansion of a paper which the author prepared on the industrial situation and which was delivered at the Birmingham Convention of the A.I.E.E., April, 1924.—Editor.

The automatic electric power station is a comparatively recent development in the art. Automatic stations were first developed for railway substations and central stations. It is natural, therefore, for automatic stations to be more widely used in these branches than in industrial power applications. Nevertheless, a promising field for automatic stations seems to be in the transformation and supply of electric power for all sorts of industrial purposes.

Electricity supply for factories, mills, mines, shops and other industrial enterprises usually lends itself quite readily to automatic operation. The kind of automatic switching equipment and its application, however, depends to a large extent on the particular requirements of the industry served.

Generally, some form of power-transforming equipment is utilized in these establishments. It may be rotating equipment such as motor-generators, synchronous converters or synchronous condensers, or it may be static equipment such as transformers. All of these have been equipped with automatic switching and control for central station and railway service and can readily be adapted to electrified industrials.

Primary power plants where water is the source are particularly well suited for auto-

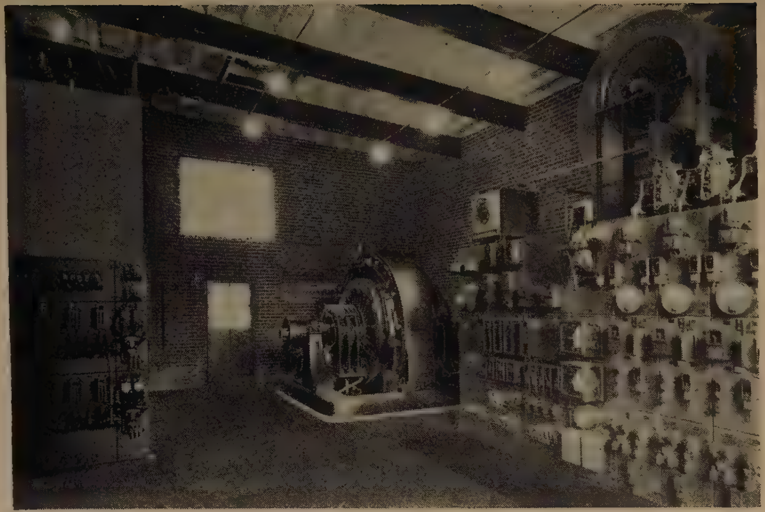

Fig. 1. Railway Substation with Synchronous Converter, 600 volts, 2000 kw., 25 cycles, 6 phase; and Portion of Six Stub-end and Multiple Direct-current Reclosing Feeders, 600 volts, 2000 amp. for Reclosing from Either Side

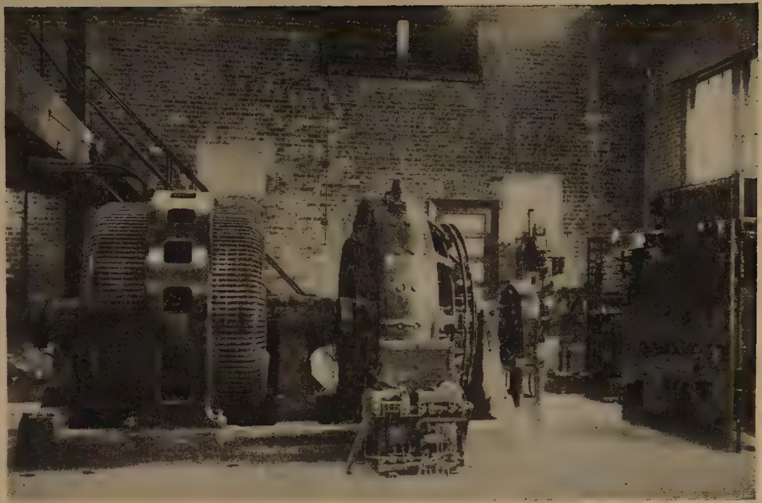

Fig. 2. Automatic Railway Substation, Showing 2000-kw., Motor-generator, High-speed Circuit Breaker and Automatic Control Panels

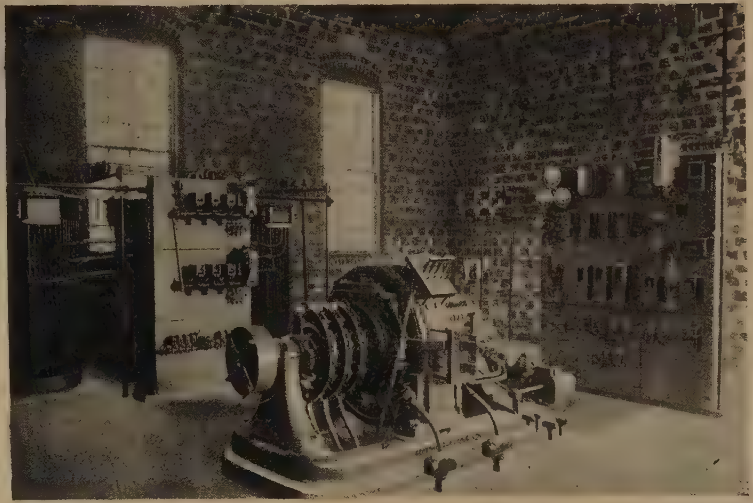

Fig. 3. Automatic Switching Equipment and Synchronous Converter, 275 volts, 200 kw., 6 phase, 60 cycles; and Combined Stub-end and Multiple Direct-current Reclosing Feeder, 275 volts, 1090 amp. for Industrial Service

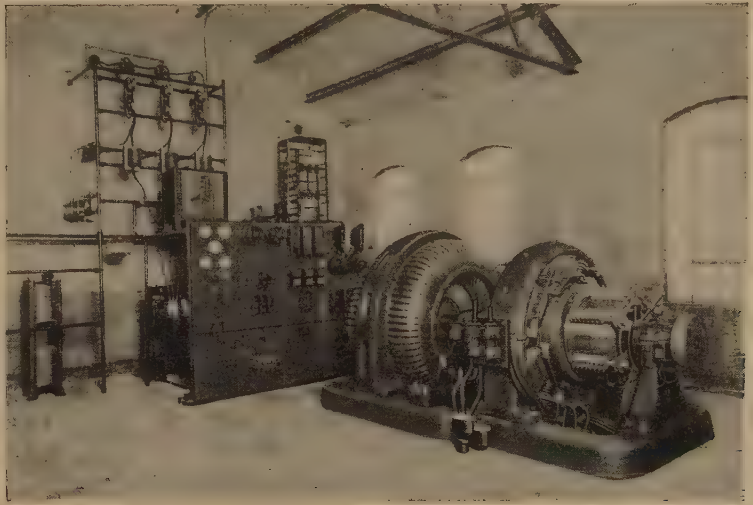

Fig. 4. 300-kw., 250/275-volt, Direct-current, 6000-volt, 3-phase, 60-cycle, Synchronous Motor-generator with Automatic Control Equipment for Industrial Service

matic control, but steam-operated stations have not yet been added to the rapidly growing list of automatic station installations.

Synchronous Condensers

Synchronous condensers form one of the simplest classes of rotating machines to which automatic station control equipment has been applied. They also form a class of power conservers which industrial organizations seem hesitant to adopt. It may be that heretofore the need to provide them with an operator has retarded their location at strategic points on the power network, or forced their location in existing attended stations which were remote from the preferred point for best performance. Whatever the reason may have been, the successful automatic operation of these units has very widely extended their field of application, particularly to electrified industries.

The first automatic synchronous condenser was a 3000-kv-a. unit installed by the Interstate Light and Heat Company at Hazel Green, Wisconsin. It was started in March, 1917, and is still in successful operation. It is located at a point on the power company's transmission lines where regulation had previously been quite poor. It more than paid for its cost in the first two years' operation. The latest automatic synchronous condenser is a 7500-kv-a. unit being installed by the New England Power Company at the Worcester, Mass., mills of the American Steel and Wire Company. In the meantime there have been a number of installations of automatic synchronous condensers but invariably by the power companies, although in most cases the condensers have been utilized for the correction of power-factor conditions caused by the industrial enterprises using the electricity.

The automatic control of a synchronous condenser is relatively simple. The starting impulse is given by any one of several familiar devices. A voltage relay, a time switch, or a simple tumbler switch may be used to start the set. The synchronous condenser is usually provided with an amortisseur winding and is brought up to speed as an induction motor. A compensator or *Y*-delta starting scheme may be used, either being readily adapted to automatic control. Usually during the period of acceleration, the synchronous condenser field remains disconnected from the source of exciting current and is bridged by a field-discharge resistor. This aids in giving the required starting and pull-in torque. After its field is excited, and the unit has been connected to the line and full pressure applied to its windings, it begins to function as a power-factor corrector. A voltage regulator which forms part of the automatic switching equipment adjusts the field current automatically to maintain fixed pressure within the limits of operation of the unit.

Automatic synchronous condensers are provided with the usual automatic station protective devices. The bearings are equipped with bearing temperature relays which will cause the set to be shut down if the bearings tend to overheat and before damage results. The machine armature is provided with current-operated thermal relays having a time-temperature characteristic similar to that of the condenser. These automatically shut the machine down if the armature current exceeds a safe value for a given time. They also permit the unit to restart automatically after a shutdown of a sufficient time duration to cool the windings. These thermal devices are of the integrating type and are self-adjusting for ambient temperatures. A grounding protective relay is also provided which causes the set to shut down in case of any leakage to ground in excess of 50 amp. This cares for any insulation failures and prevents undue damage. Single-phase starting, harmful single-phase running, reverse phase, loss of field, too low line pressure, short-time alternating-current overload, etc., are also cared for by the usual automatic station relays.

Synchronous Motor-generators

Synchronous motor-generators form the next general class of rotating electrical machines which have been successfully equipped with automatic switching. Units of 150 kw. in capacity are now operating in many sections of the coal mining district and are typical of the smaller sizes. A 2000-kw. set is in operation on the 666-volt direct-current electrification on the main line of the New York Central Railroad and is typical of the larger sizes applied to very severe operating conditions. These units may be started on load demand, or at a pre-determined time, or by a tumbler switch or its equivalent. The automatic switching equipment proceeds to function immediately the starting impulse is given. First, it checks the line pressure to be sure it is ample to start and run the set. Next, it checks the supply to be sure all the phases are intact and are of the correct sequence. Then, it checks the bearings, machine windings, and ambient temperatures, to be sure these will permit the machines to run if and when started. Next, it connects the motor to the source of power, either through a compensator or to taps on the transformer, or through the transformers direct if *Y*-delta starting is used. Then the set starts to rotate and increases in speed. At synchronous speed, the automatic switching equipment again takes hold and connects the field circuit to the source of the exciting current. When field current has been established, the set is transferred from the starting combination to the running combination. During the accelerating period the motor field remains disconnected from the source of exciting current and is bridged by a resistor in the same manner as is the synchronous condenser during its starting cycle. This permits individual adjustment of each motor so as to obtain a complete start under practically all conditions which can be found in service.

In the larger sets, a low value of field is applied while on the starting tap, and the final value after the machine is transferred to running connections. In the smaller sets, the final value is applied in one step while on the starting tap. The smaller sets having 250-volt or 275-volt generators are usually excited directly from the generators. Those rated for higher pressures or arranged with voltage regulators are usually fed from an exciter either separately operated or direct connected.

The synchronous motor-generator set has the usual automatic station protection to prevent runaway, operation without field, harmful single-phase operation, leakage to ground, short-time and long-time continued overload, bearing temperature, etc. Some of these devices, such as the bearing temperature relays, are hand reset where continued operation of the machines under any circumstances might lead to their destruction. The number of such devices, however, is a minimum so as to insure continuity of service under all conditions, excepting where the machine might fail and thus interrupt such continuity for a long time. Most of the other protective devices, such as the long-time delay overload relays, phase-checking relays, etc., are automatically reset and permit the equipment to resume normal operation as soon as the unusual conditions have been corrected.

The direct-current generator is provided with protection and adjustment, depending upon the service requirements to which it will be subjected. The simpler equipments, which may be shunt or compound wound, are usually operated with a fixed shunt-field setting. This setting is chosen to give the desired terminal pressure, and must be carefully adjusted to give the correct loading of the machines. Multiple-unit stations also require careful compounding of the units to permit the successful multiple operation of "hot" and "cold" machines.

Larger sized sets have their direct-current generators frequently provided with automatic load regulation. One type is provided with a shunt-field bucking scheme. The shunt-field current is normally furnished by the generator itself. The current is then passed through the armature of a tiny motor-generator continuously rotating. This set, by a suitable raising or lowering of its field current, bucks or boosts the shunt-field current of the generator the correct amount and gives the desired regulation. In one example, using this method of control, load swings from 300 per cent normal to 200 per cent reversal are successfully handled.

Another modification is a compound-wound direct-current generator with the series field connected to oppose the shunt field. This type of generator is usually operated with the series field shunted by a circuit breaker which allows only a fraction of normal current to flow through the field when it is closed. Under heavy overload conditions, the circuit breaker is automatically opened and the series field carries the full line current. Under this condition it tends to oppose the shunt field. Now by suitably proportioning the shunt and series fields, the direct-current generator can be made practically a constant-current machine and service may be maintained at a reduced pressure during emergency load conditions. As soon as the overload condition ceases, the circuit breaker automatically recloses and shunts the series field. A number of such equipments are operating on the Edison three-wire networks of many of the large electricity supply corporations, and their use is being very rapidly extended. Their judicious application to electrified industrial establishments would insure continuity of service under the most severe conditions short of complete and sustained interruption of primary electricity power supply.

Synchronous Converters

Synchronous converters form without exception the largest single class of rotating electrical machines which have been successfully provided with automatic switching equipment: in fact, they were the first electrical machines to be so equipped. This is principally because of the almost universal application of synchronous converters for interurban railway service where automatic stations were first widely adopted following the Union, Ill., installation in 1914.

The automatic switching and control of synchronous converters assumes the alternating-current supply to be available before any starting operations are performed. Consequently, all automatically-controlled synchronous converters are invariably alternating-current starting. Also, with one or two minor exceptions, the starting is accomplished with the aid of an amortisseur winding on the field.

The starting indication for an automatic synchronous converter may be any one of the usual devices, such as a pressure relay, a time switch, a tumbler switch, or their equivalent. Immediately the starting impulse has been completed, the synchronous converter is connected to the starting taps on the power transformer. One-third taps or one-half taps, depending on the design of the synchronous converter and transformers, will usually furnish sufficient torque to start the converter armature and pull it into step. During the starting operation, the shunt field is usually opened. After the machine has reached synchronous speed, its field is either flashed with the correct polarity before it is made self-exciting, or its field is reversed until correct polarity is established. Then the converter is automatically transferred from the starting taps to the running taps.

The next step in the process is to connect the synchronous converter to the direct-current network or feeder, and here the inherent characteristics of the converter require a different series of operations than do motor-generator sets. The direct-current terminal pressure of a synchronous converter is regulated largely by the alternating-current pressure supply. Only a relatively narrow range of direct-current terminal-pressure adjustment is possible by field adjustment. This then requires some arrangement for safely connecting the synchronous converter to the direct-current network, even though that network may be operating at a pressure quite different from the terminal pressure of the synchronous converter. This condition is usually encountered in all sorts of electric haulage installations, since here the wide swings in power demand are very large compared with the feeding capacity of the alternating-current supply. For electric railways and commercial electric power service generally, and sometimes for industrial electric power supply, synchronous converters are equipped with load-limiting resistors. These are connected between the direct-current terminals of the synchronous converter and the direct-current network or feeder after the synchronous converter has been placed in complete running condition insofar as the alternating-current side is concerned. These resistors are then usually shunted out in two or three steps thus gradually loading the synchronous converter from the direct-current network. The shunting contactors or circuit breakers used for this service are usually provided with current relays having interlocks so that the synchronous converter cannot be loaded beyond its capacity. Other devices such as thermostats, located near the load-limiting resistors, permit the synchronous converter to supply current to the direct-current system within safe heating limits until the load is reduced or the resistors and converter tend to overheat dangerously. Under these conditions, the converter is automatically shut down until it and the resistors cool. After the equipment has cooled sufficiently, a fresh start is automatically made.

The load-limiting combination available for, and used with, synchronous converters permits their wide application to all sorts of electrified industries as well as to electric railway and electric power supply systems.

Synchronous converters for automatic operation are provided with the usual automatic station protective features such as bearing and resistor temperature relays, short- and long-time continued alternating-current overload relays, single-phase starting preventive and harmful continued single-phase running preventive relays, low alternating-current pressure starting or operating preventive relays, overspeed switches in combination with a shunt trip circuit breaker, leakage to ground relays, etc.

Other electric power-transforming machines, such as balancers, and static transformers, have been made completely automatic and are now in successful operation. Their design usually takes pattern after the best manual operation scheme, except that the time for the switching is generally reduced from a matter of minutes to a matter of seconds.

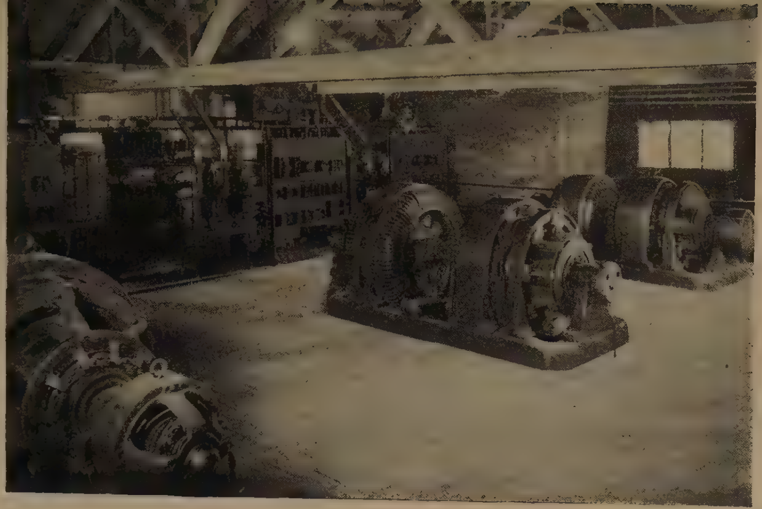

Fig. 5. Automatic Station Control Equipment and Synchronous Motor-generator Sets for Edison Three-wire Service

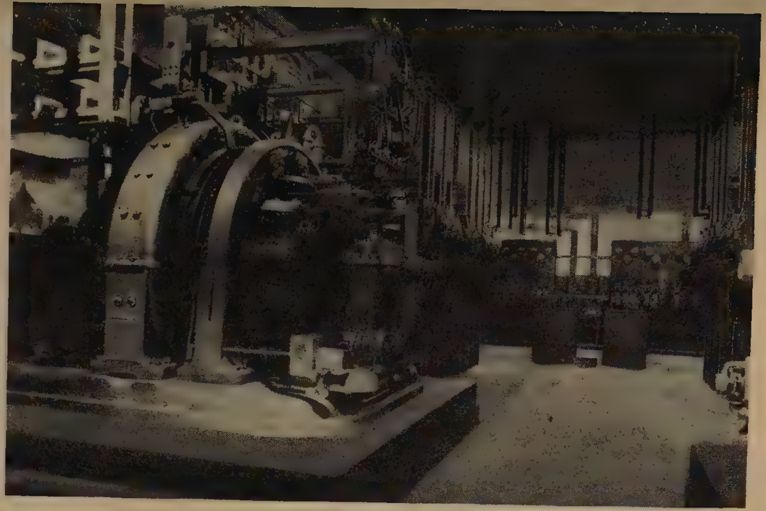

Fig. 6. One of Two 250-volt, Direct-current, 1500-kw., Automatically Operated Synchronous Converters and Portion of Control Apparatus for Edison Three-wire Service

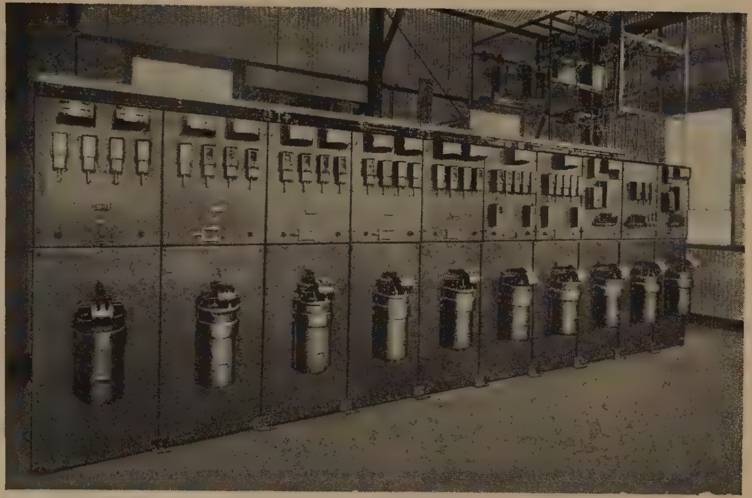

Fig. 7. Automatic Switching Equipment for Five 2-phase and Two Single-phase, 2200-volt, 60-cycle Reclosing Feeders and Automatic Transfer Apparatus for Two Incoming Lines

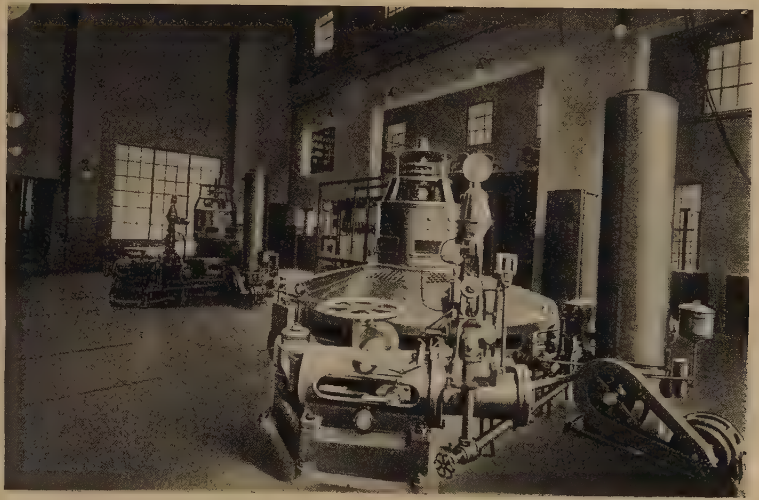

Fig. 8. Automatic Station Control Equipment with 2000-kv-a., 2300-volt, 60-cycle Waterwheel Generators

Hydroelectric Plants

The automatic hydroelectric plant is one of the outstanding applications of automatic switching equipment to industrial enterprises. Consider, for example, the many streams of moderate size but relatively uniform flow which are found in the upper Middle West. They have been used for many generations to drive grist mills of quite good size, as well as performing many other industrial functions of varied natures. The hydro equipment which has heretofore been used is fast becoming antiquated and the output of the mills is suffering in consequence. The recent installation of automatic hydroelectric equipments in a number of these mills has wrought an important change in this section of the country. The same streams now permit not only a greater mill output in combination with the electrification of the mills, but also provide an inexpensive power supply to adjacent towns and villages. More important even is the fact that the electrified mill can now be connected to the large electric power supply system covering the country, and can either take power from this system during times of low water or can feed power into the network during times of high water.

Synchronous generators are almost exclusively used for automatic hydroelectric stations since they can be provided with their own exciters. They usually have a waterwheel equipped with either an oil pressure governor, a servo-motor, or motor-operated gates. The synchronous generator is usually provided with an amortisseur winding to assist in pulling the machine into step. The starting impulse is given by any one of the familiar relays or by a push button, or may be given by making alive the station feeder from an alternating-current network. Immediately after the starting impulse is completed, the waterwheel gates are opened and the waterwheel started. When the machine reaches about 95 per cent normal speed, the armature is connected to the alternating-current network, either directly or through transformers and immediately thereafter the field is excited. This brings the generator into phase with the network and places load on the machine.

Automatic voltage regulators are generally furnished with automatic hydroelectric stations. These, in combination with the hydraulic regulating equipment, adjust and maintain the desired load on the equipment.

Automatic hydroelectric stations are provided with only such protective features as are needed for the quite simple machinery involved. Excess speed, excess electric pressure, insufficient oil pressure, bearing and machine heating, short- and long-time continued overloads, together with loss of field, each has its protective devices, which make the automatic hydroelectric station economical and safe in sizes up to 8000 or 10,000 kw.

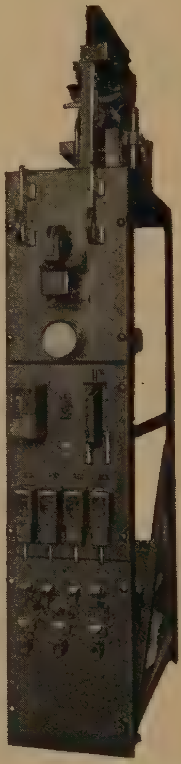

Fig. 9. Automatic Switching Equipment for Combined Stub-end and Multiple Direct-current Feeder, 600 Volts, 800 Amp., with High-speed Circuit Breaker, for Reclosing from Either Side

Transformer Stations

Transforming stations using static transformers form a very important class of industrial and power units to which automatic control has been successfully applied. In some systems transforming stations using a single transformer or a single bank have been standardized. In other installations two or more transformers or transformer banks form the basis of the design.

Where a single transformer or transformer bank is the station unit, there is usually a single incoming high-tension line or possibly two such lines. Where there is a single line the switching equipment is provided merely with an overload trip; no attempt being made to close the high-tension feeder at the station in case it should be tripped due to overload or transformer trouble. If there are two incoming high-tension lines to the station having a single transformer or single bank, then one line is usually the preferred or normal source of power for the station and the other line is usually the emergency source. These two lines are provided with automatic switching equipment of such a character that so long as the normal source is intact it furnishes power to the station. If for any reason the normal source is interrupted, then the emergency source is automatically connected to the station and supplies power until the normal source is restored, whereupon the emergency source is disconnected.

Transforming stations having two or more transformers or banks of transformers are usually provided with two or more incoming high-tension lines. In addition the high-tension bus is usually so sectionalized that a single transformer or bank is normally connected to a single section of the bus. Stations of this character are designed so that when the load on the station is light one transformer or one bank supplies power to all the sections of bus from one incoming line. When the load is heavier a second transformer or second bank supplied by power from the second line is thrown into service and the bus is sectionalized so that each bank and each line feeds its own section of bus. If the station is of sufficient capacity to warrant more transformers or transformer banks this scheme may be extended so that at the heaviest loads additional sections of the bus may be fed by separate transformers or banks of transformers, each of which is fed from its own line. As the load on the station diminishes, the number of transformers are diminished until the lightest load finds the station being supplied by one line through one transformer bank. These stations in addition to being provided with one line per transformer bank are usually provided with one additional emergency line sometimes with and sometimes without a separate transformer or transformer bank. This emergency line is so arranged that in case of failure of any one of the normal lines it will be connected into service in place of the line which is out of service. When the normal source is restored the emergency line is disconnected.

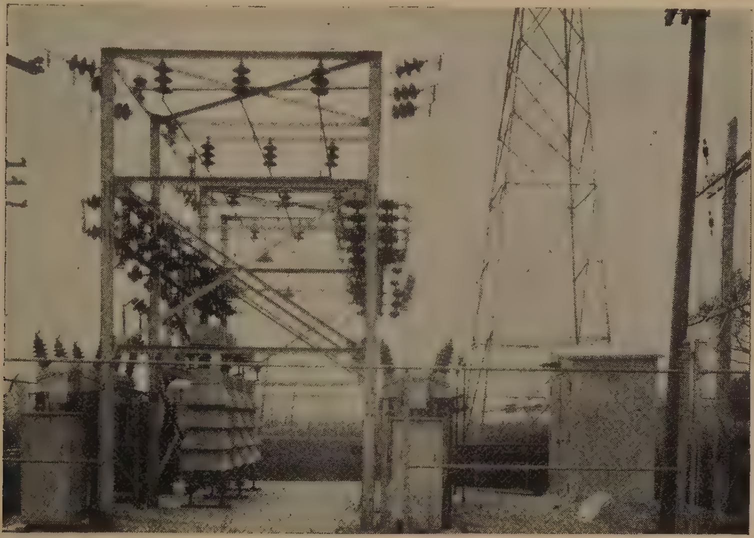

Fig. 10. Outdoor Incoming Line Equipment and Automatic Alternating-current Reclosing Feeder Station

All of the operations just described apply to the high-tension side of the power transformers. They are performed automatically and by means of relatively simple equipment. A motor-operated master switch is sometimes used for fixing the sequence of operations of the various switching devices and the equipment has been so standardized that even for a station having four incoming lines with four transformer banks only four switchboard panels 90 in. high and 24 to 28 in. wide are required for the entire automatic switching equipment.

Alternating-current Feeders

Alternating-current feeders from transforming stations having static transformers may be made automatic reclosing. Mechanisms are now available for closing the oil circuit breakers with either direct or alternating current and for tripping them from either kind of a source. The most economical installation provides alternating-current motors with suitable mechanisms for closing the oil circuit breakers and a direct-current source for tripping them. In this way the direct-current source may be a relatively small storage battery which can be trickle-charged from the alternating-current service. The feeders are so arranged that they trip on overload, remain open a definite length of time and then reclose. If the overload or short circuit still exists on the feeder the oil circuit breaker is then again opened, waits a given length of time and is reclosed. Depending upon the design, these trippings and reclosures follow each other at equal time intervals or at unequal time intervals depending on the nature of the service for which the operating company is obligated.

In addition to being provided with these tripping and reclosing features, the feeders are provided with one or two types of locking-out devices. Usually they are provided with a lockout device which operates if the feeder is reclosed successively two or three times and then is opened. The device locks the breaker in the open position since two or three trials have demonstrated that the feeder is permanently overloaded or short circuited. Sometimes an additional lockout device is provided where the oil circuit breaker capacity is not sufficient to take care of several reclosures on the maximum short-circuit current which might be obtained. For such conditions it is usual to provide the second locking device which operates and locks the breaker open after any circuit interruption in excess of a given current value.

Direct-current feeders form a very important class to which automatic switching equipment has been applied. These feeders are usually designed so as to trip automatically on short circuit or overload or on short circuit only. For overload tripping, the usual overload relay is used either separate from the circuit interrupter or forming a part of it. For tripping on short circuit a bucking bar which carries current to buck the holding coil of the circuit interrupter is customary. After the circuit interrupter has been opened, either by overload or by short circuit, it remains open until the overload or short-circuit condition has been removed.

Two general types of equipment are used for determining when the external circuit is ready to be closed. One scheme is known as the load-limiting scheme. The other is known as the load-indicating scheme.

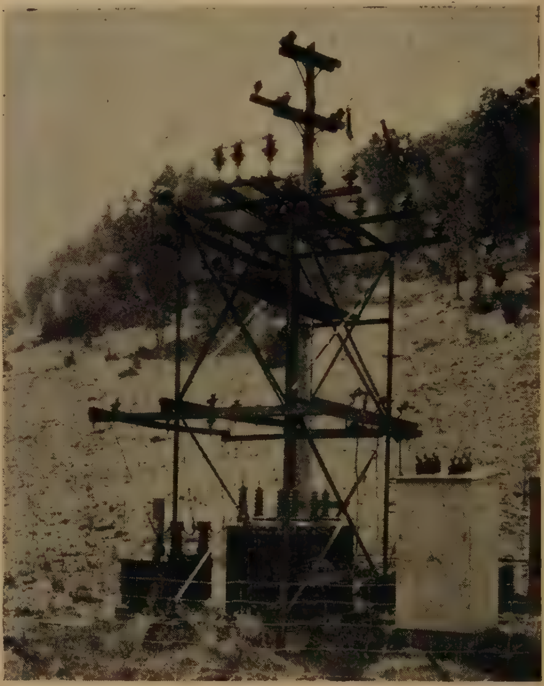

Fig. 11. Outdoor Automatic Alternating-current Reclosing Feeder Station

Feeders equipped with the load-limiting scheme are provided with a resistance which is normally shunted by the circuit interrupter when it is closed. If the circuit interrupter is opened by short circuit or overload on the feeder, then the resistance is connected in circuit between the source of power and the feeder. Current is then continued to the feeder but at a diminished pressure depending on the resistance of the short circuit and for a time depending on the setting of the feeder and the load-limiting resistor. The resistor is always provided with a thermal device which operates when the integrated current for a given time tends to raise the temperature of the feeder and resistor toward a dangerous point. This thermal device then automatically disconnects the feeder from the bus and reconnects it when the feeder and resistor have cooled to a safe point. With this type of equipment, current is continued to the feeder as long as it is safe to pass it and full pressure is restored to the feeder immediately on the removal of the overload or short-circuited condition.

Feeders provided with load-indicating resistors for reclosing circuits may be divided into two general classes. One class uses intermittent feeling-out with a load-indicating resistor while the other class uses continuous feeling-out with a load-indicating resistor. The intermittent feeling-out equipment generally uses about 600 amp. and feels out the circuit about every 10 to 30 sec. It is so designed that after the circuit interrupter has opened the feeder circuit the automatic feeling-out equipment is brought into service. At intervals it throws about 600 amp. through a resistor onto the feeder and continues this until the feeder circuit gives indication that it has been cleared of overload or of short circuit whereupon the circuit interrupter automatically recloses and resumes supply of power of full pressure to the feeder.

Feeders provided with continuous feeling-out generally use a current not in excess of two per cent of the normal rating of the feeder for this purpose. Immediately the circuit interrupter opens due to overload or short circuit, a resistance which will limit the current flow into the feeder at full bus pressure is connected into the circuit. This resistor is also connected to suitable relays which measure in effect the external resistance of the feeder. As soon as the feeder circuit has been relieved of overload or short circuit, the combination of relays and resistor causes the circuit interrupter to reclose and automatically reconnect the feeder to the source of normal pressure.

Each of these varieties of direct-current feeders has its advantages. Each of them in addition has its peculiar limitations. For example, load-limiting feeders may be provided with resistors for a given current carrying capacity for a definite time. The size of this resistance depends upon the service and the cost depends almost directly on the weight of iron in the resistor.

Feeders provided with load indicating resistors have also a peculiar feature which is necessary to recognize. Again this peculiarity is associated with the resistor used for load-indicating purposes. The value of this resistor in ohms determines the maximum reclosing point of the equipment. Some equipments using a resistor which will pass only a small current will reclose at only about 20 per cent of the normal rating of the feeder while other designs using a larger feeling-out current will reclose up to normal current carrying capacity of the feeder. Each design has its particular application and care should be exercised in the selection to be certain that for any given application the reclosing features are as correct as the tripping features.

Suggestions

To obtain the utmost from any automatic installation a very careful study must be made of the system to which the automatic equipment is to be applied and at the same time a thorough knowledge must be obtained of the automatic station equipments which are available. A correct choice of equipment for a given set of operating conditions will effect economies in operation and distribution which in a year or two will more than repay the first cost of the automatic equipment, besides effecting wonderfully improved service to consumers.

Developments in Electric Drive for Central Station Auxiliaries

By J. W. Dodge

Central Station Engineering Department, General Electric Company

Central station auxiliaries when driven electrically are more economical and reliable, and cost less to maintain, than when steam driven. To obtain the full benefits of electric drive, however, much depends upon the proper selection of suitable motors and control. The following article has therefore been written to describe various types of motors and control for this service, to explain their inherent characteristics, and to outline their applications. The information should be very helpful in arriving at the best choice of electric drive equipment for power plant auxiliaries.—Editor.

Practically all of the steam power plants now being designed or built, which fall in the Central Station class, are using steam bled from the main units for feedwater heating and thereby obtain a higher plant efficiency than is possible by using the older scheme with steam driven auxiliaries and utilizing the exhaust steam from these for heating the feedwater. This change in the heat cycle of the plants, together with the fact that extremely high steam pressures and temperatures are being used, has made the use of electric drive for auxiliary apparatus more attractive than the use of small high-pressure steam turbines or reciprocating engines. The reliability of an induction motor is considered higher than that of such steam equipment, and the maintenance of the steam turbine and high-pressure steam piping is high as compared with electric drive. It is of course necessary to supply an unfailing source of electric power. Some stations are provided with steam turbines for emergency operation of the most important auxiliaries, or duplex units with a motor and turbine both connected to the same auxiliary unit. These are used principally on boiler feed and condenser pumps.

Most central stations produce alternating-current power and this is being quite generally used for driving the auxiliaries. Alternating-current motors are simple and dependable and adjustable speed is obtained by using a wound rotor and pole changing induction motor, or brush shifting alternating-current commutator motors, which are now available in both shunt and series types. Where wide speed ranges are required, direct-current motors are sometimes necessary or desirable, and are often used for operating stokers and fans. These auxiliaries may require rather accurate speed adjustment over a wide range. This is particularly true where powdered coal or oil is used for fuel, as just the right amount of air must be supplied at all times to burn the fuel properly.

Electric drive is particularly well adapted to remote or automatic control, and many central-station designers are taking advantage of these features for the auxiliaries. Group control or centralized control of boiler-room auxiliaries is quite common practice.

It is of primary importance to have motors and control such that in case of momentary voltage failure the auxiliaries will automatically restart. This is accomplished by the use of squirrel-cage motors designed for full voltage starting, and by modifications in control of slip-ring and commutator type motors which insure sufficient starting torque from the motors to start the auxiliaries.

The switching equipment required for auxiliary power circuits is becoming an important item in the modern central station due to the increasing amounts of power to be handled at 2300 volts. It is not unusual to find that switches with upwards of 100,000 kv-a. rupturing capacity are required for 2300-volt auxiliary feeder switches in the larger generating stations.

MOTORS

The following is a list of the more important motors available for driving station auxiliaries:

Alternating-current Motors

1. Constant-speed motors.
    - (a) Single-squirrel-cage induction motors.
    - (b) Double-squirrel-cage induction motors.
    - (c) Wound-rotor induction motors.
    - (d) Synchronous motors.
    - (e) Super-synchronous motors.

2. Variable speed motors.
   - (a) Wound-rotor induction motors with secondary speed control.
   - (b) Wound-rotor motor with pole changing stator windings.
   - (c) Squirrel-cage multi-speed pole changing motors.
   - (d) Shunt characteristic alternating-current commutator motors.
   - (e) Series characteristic alternating-current commutator motors.

Direct-current Motors

- (a) Compound-wound motors for constant speed and variable speed.
- (b) Shunt-wound variable speed motors.

Where the speed range is high and regulation is desired by shunt-field control, compensated motors are desirable. These are shunt-wound motors fully compensated for wide speed range.

Full-voltage Starting of Alternating-current Motors

Standard lines of squirrel-cage induction motors are not usually designed for full voltage starting (except in small sizes). Certain of these motors are, however, suitable for starting on full voltage. Others require extra bracing of the stator winding. The starting current varies considerably for different ratings. It is usually between five and eight times normal full-load current. The starting torque varies considerably but is usually quite high (around 115 to 150 per cent normal).

The double-squirrel-cage motor has been designed to meet the requirements of a full-voltage starting motor that will give smoother starting than the standard squirrel-cage motor and will draw less starting current from the line.

Where slip-ring motors are used with hand control and without low-voltage relay protection, the motors can be made self re-starting by the use of a contactor for operation on low voltage to cut in secondary resistance and automatically cut out again after a suitable time delay on the return of alternating-current voltage.

Commutator type alternating-current motors are self starting and may be thrown on full voltage at any brush position which provides sufficient torque to start the load. The shunt-characteristic brush-shifting motor is particularly desirable because of the fact that it requires no control equipment other than a suitable line switch. The speed control of these motors is obtained by shifting the brushes and the starting torque and starting current may be varied by changing the brush position.

Double-squirrel-cage Motors

The double-squirrel-cage induction motor is designed to draw a relatively low starting current. The motor might be used to advantage in many applications for driving central station auxiliaries where full-voltage starting is desired. There are several features pertaining to the design and characteristics of this motor which should be understood, the following being particularly pertinent:

The rotor windings may be designed for starting torque as low as 75 per cent or as high as 250 per cent with the same maximum output at full speed.

The maximum output at full-load speed largely determines the starting current. For central station auxiliaries, it is desirable that the motor be designed to deliver its rated load on two-thirds voltage; which, in turn, means its maximum output must be at least 225 per cent on normal voltage. With this output, the starting current at full voltage cannot be less than about 425 per cent normal full-load current with rotor windings designed for 100 per cent starting torque and about 475 per cent normal full-load current with rotor windings designed for 250 per cent starting torque.

With rotor windings designed for 100 per cent starting torque, the full-load efficiency is approximately the same or slightly better than the standard single-squirrel-cage motor. The power-factor will be somewhat lower (3 to 5 per cent).

With rotor windings designed for 250 per cent starting torque the efficiency will be slightly lower (about 1 per cent) than the standard single-squirrel-cage motor and the power-factor about 5 to 7 per cent lower.

With rotor windings designed for intermediate values of starting torque the efficiency and power-factor will be between these values.

Since the maximum output is not affected it is obvious that, for such drives as centrifugal pumps, there is no object in designing the rotor windings to give the highest starting torque. A starting torque of 100 to 150 per cent will take care of most applications to central station auxiliaries.

The double-squirrel-cage motor has the following advantages over the single-squirrel-cage motor:

(a) Lower starting current.

(b) Greater safety due to lower stresses on the stator winding during starting.

(c) Greater flexibility in design as to starting torque.

(d) Larger capacity for starting heavy flywheel loads on account of greater volume of metal in the rotor windings, and consequently greater rotor heat capacity.

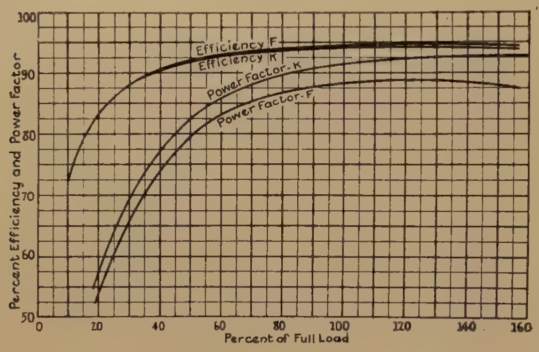

Fig. 1. Comparative Efficiency and Power-factor Curves for 225-h.p., 1200-r.p.m., Single- and Double-squirrel-cage motors; curves *K* are for single-squirrel-cage motors; and curves *F* are for double-squirrel-cage motors

The double-squirrel-cage motor has the following disadvantages as compared to the standard squirrel-cage motor:

(a) Lower power-factor, and in case of extremely high starting torque, lower efficiency.

(b) Higher cost. This is liable to vary from about 20 per cent for the low-torque double-squirrel-cage motor to about 30 per cent for the high-torque double-squirrel-cage motor.

Application of Double-squirrel-cage Motors

The double-squirrel-cage motor should be considered for constant-speed service where full-voltage starting is required and where the horse power per pole exceeds about 15. This would correspond to the following:

1800 r.p.m.—50 h.p. and larger.
1200 r.p.m.—75 h.p. and larger.
900 r.p.m.—100 h.p. and larger.
720 r.p.m.—150 h.p. and larger.

The low-torque double-squirrel-cage motor should be considered for any capacity where smooth starting on full voltage is desirable. It should be considered for any capacity where high starting torque is necessary. It should be considered for any capacity where the machine to which the motor is applied has a large flywheel effect.

Characteristic Curves of Double-squirrel-cage Motors

The curves shown in Fig. 1 and Fig. 2 give comparative characteristics of single- and double-squirrel-cage motors. It should be kept in mind that such characteristics vary considerably for different ratings, and that the starting current and torque curves shown for the single-squirrel-cage motor are representative of large high-speed motors only (and are considerably higher than for low-speed squirrel-cage motors). These curves show the starting current to be 10 times normal at starting which gives 190 per cent of full-load torque. The starting current of the average single-squirrel-cage motor is from six to seven times normal full-load current, so that the curve is hardly typical of this class of motors since it makes the starting current taken by the double-squirrel-cage motor appear to be a smaller proportion of the starting current of a standard motor than is usually the case.

The starting torque of the double-squirrel-cage motor can be varied considerably (from 100 to 250 per cent normal full-load torque) by changes in the design of the winding with little change in the starting current.

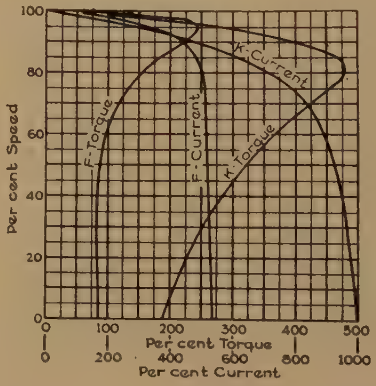

Fig. 2. Comparative Torque and Starting Current Curves for 225-h.p., 1200-r.p.m., Single- and Double-squirrel-cage Motors; curves *K* are for single-squirrel-cage motors; and curves *F* are for double-squirrel-cage motors.

Polyphase Brush-shifting-shunt Motors

The development of the shunt-characteristic three-phase motor (Fig. 3) is the result of a demand for an alternating-current adjustable-speed motor for applications where a shunt speed characteristic is necessary or desirable.

The primary and secondary windings of this motor are similar to those of a standard slip-ring induction motor except that the primary winding is placed on the rotor and the supply lines are connected to the slip rings. In the same rotor slots there is provided a second winding known as a regulating winding which is constructed like a direct-current armature winding and connected to a commutator. The stator is provided with a phase-wound secondary winding and each phase is brought out separately, one end of the phase to one brush yoke and the other end of the phase to another brush yoke. These brush yokes are mounted one at each end of the commutator and are shifted by a handwheel mechanism so constructed as to move the brush yokes in opposite directions.

The secondary winding is so connected that the circuit through each phase is completed by means of the commutator. When the brushes of both yokes are in line on the same commutator bars, the secondary phases are short circuited and the motor operates as an induction motor. Inasmuch as the regulating winding is placed in the same slots as the primary winding, an alternating voltage of constant value is induced in the regulating winding by the primary flux. As the brushes are moved apart, a section of the regulating winding is included in series with the secondary winding, thereby injecting into the secondary circuit a voltage which, by proper design, has the effect of changing the speed of the motor.

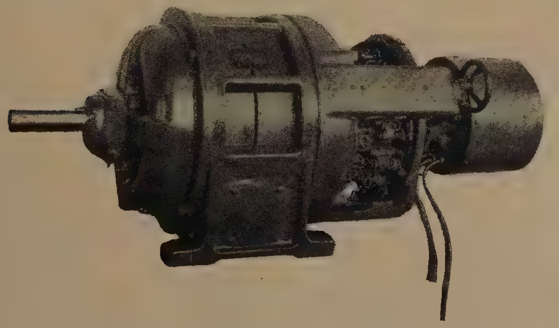

Fig. 3. 30/10-h.p., 1250/415-r.p.m., 550-volt Adjustable-speed Shunt-characteristic Brush-shifting Motor

The electrical circuits of the motor are simple and are nothing more or less than those of a slip-ring induction motor with a few turns of a regulating winding in series with the secondary. The operation is likewise comparable with that of an induction motor with a somewhat increased value of slip.

For minimum starting current the brushes are set in approximately the low-speed position, at which point the motor will give about 150 to 200 per cent starting torque with about 125 to 160 per cent full-speed line current. Maximum running torque varies from the same value as starting torque in the low-speed position to approximately 350 per cent in the high-speed position.

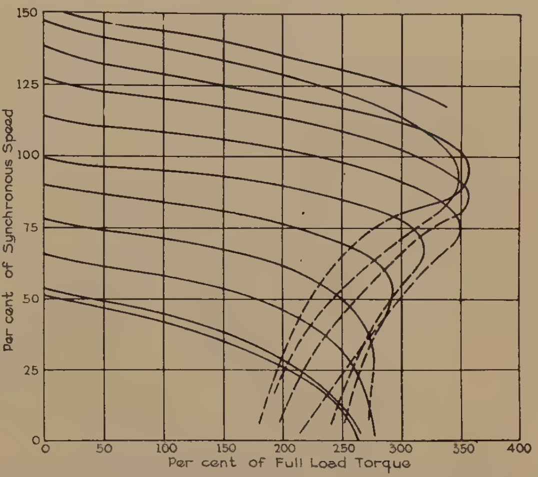

Fig. 4. Speed-torque Characteristic Curves of Shunt-characteristic Brush-shifting Alternating-current Motor Typical of 60-cycle Motors from 5 to 15 h.p.

As an indication of efficiency and power-factor values, it may be pointed out that one of the larger motors has a test efficiency at full-load torque at ⅓, ⅔ and full speed points of 72, 80 and 79 per cent respectively, and corresponding power-factor of 63, 83 per cent and slightly leading. Corresponding values of efficiency for a wound-rotor induction motor operating at corresponding speeds by means of secondary resistance are 28.5, 62 and 86 per cent respectively with power-factor at 88 per cent at all speeds.

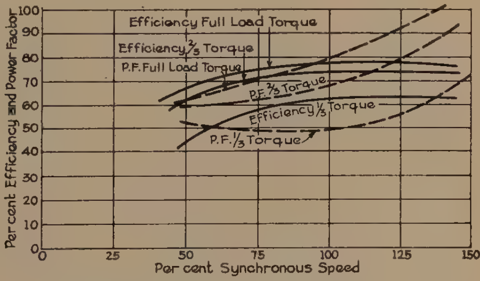

Fig. 5. Efficiency and Power-factor Curves for Shunt-characteristic Brush-shifting Alternating-current Motors Typical for Sizes 5 to 15 h.p.

The motor is self contained, no auxiliary devices being required other than a switch for connecting the motor to the line, where hand control can be used for speed control.

A line of these motors has been developed for three-phase, 60-cycle, 220-, 440-, or 550-volt circuits for ratings from 5 to 50 h.p. inclusive.

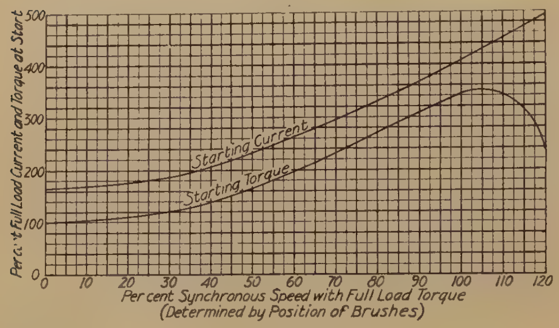

Fig. 6. Starting Characteristic Curves of Series Type Brush-shifting Alternating-current Motors

While the standard line of motors is limited to the 50-h.p. size as a maximum, several motors of larger size are now being built, including 25-cycle motors in 500- and 600-h.p. sizes which will be used for steel-mill main-roll drives. The maximum rating of this type of motor is limited to about 10 to 15 h.p. per pole for 60 cycles, and 40 h.p. per pole for 25 cycles.

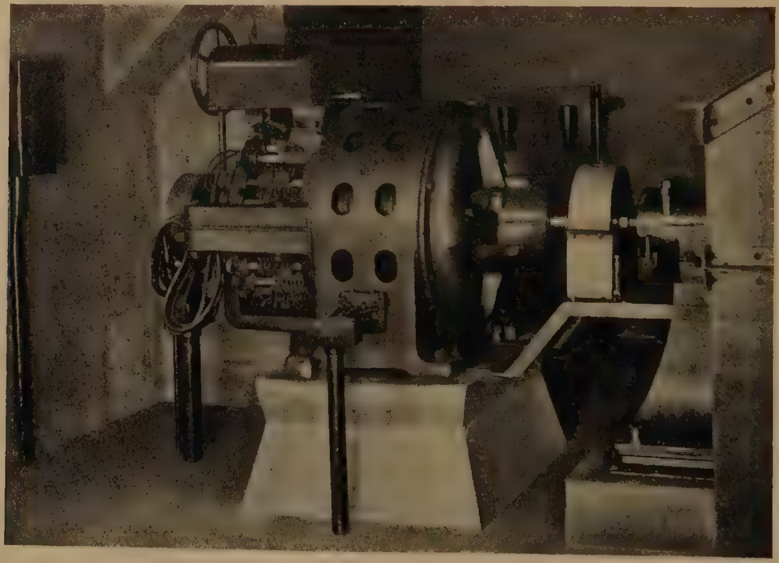

Fig. 8. 150-h.p. Automatic Brush-shifting Motor Driving a Forced Draft Fan

Figs. 4 and 5 show typical characteristic curves for polyphase brush shifting shunt motors of sizes from 5 to 15 h.p., at high speeds, designed for 3 to 1 speed range. These are the sizes generally used for stoker drive, and Fig. 4 shows the large overload torque capacity of these motors.

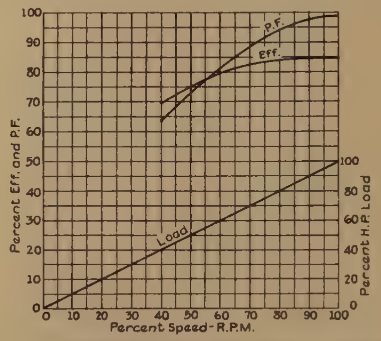

Fig. 7. Efficiency and Power-factor Curves of Series Type Brush-shifting Alternating-current Motors

Each curve represents the characteristic of the motor for a single brush position. The particular motor on which these curves were taken had a maximum rated speed of 1550 r.p.m.

The lower curve is for the low-speed brush position and shows the starting torque to be about 260 per cent of normal. At this brush setting the current input to the motor was 175 per cent of normal full-load current. As the brush position is advanced toward the high-speed position, the starting current increases and the torque decreases, until at the highest speed setting the motor develops a starting torque similar to a wound-rotor induction motor with secondary short circuited.

In other words, at the low-speed brush position, the polyphase brush-shifting motor has better starting torque per ampere line current than other motors, either alternating- or direct-current, and as the brushes are shifted to the higher speed positions this starting efficiency gradually falls off.

The torque characteristics show this type of motor to be especially well adapted to stoker drive, where high overload torque capacity is essential to prevent stalling when hard chunks of coal enter the stoker, when clinker beds form, etc.

The speed change on these motors being continuous (not by steps) makes exact speed control possible. The torque characteristic curves, particularly on the larger motors, show the regulation to be very flat from no-load to full-load torque at all speed settings.

There is some flexibility in the design of these motors as to relative efficiency and power-factor at the various loads and speeds; and where motors are to operate at or near some particular speed and load the majority of the time, the motors can be designed for high power-factor and efficiency at these particular points, sacrificing somewhat in these characteristics at other points on the curve.

Variable-speed Series-characteristic Brush-shifting Motors

This motor consists of a rotating member similar in appearance and design to a direct-current armature. The windings are connected in series through the brushes with the secondary of a transformer. The stator winding, similar to that of an ordinary induction motor, is connected in series with the primary of the transformer. The transformer reduces the voltage that has to be commutated and, because of its saturation characteristic, limits the no-load speed of the motor to a safe value.*

Figs. 6 and 7 show typical characteristic curves for this type of motor, and Fig. 8 shows a typical installation of a motor direct-connected to a forced draft fan.

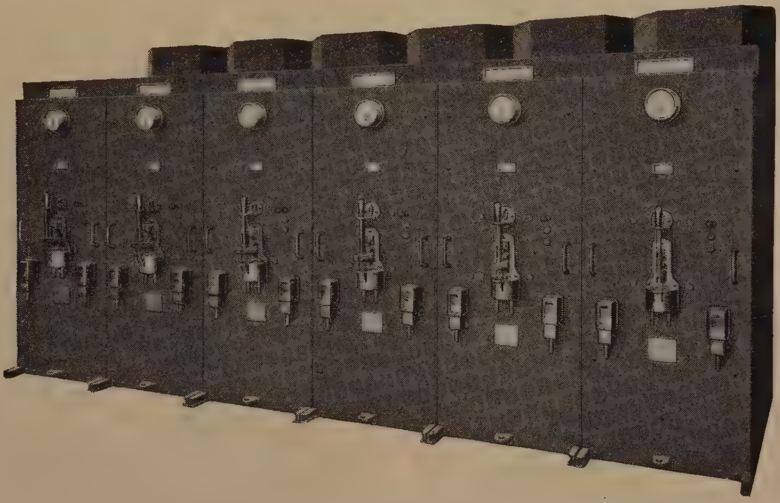

Fig. 9. Safety, Inclosed Unit, Removable Truck Type, Feeder Switchboard

INTERESTING APPLICATIONS OF CONTROL EQUIPMENT TO POWER PLANT AUXILIARIES

The use of truck type switches for feeder and selector switches is desirable since this makes possible the quick replacement of any switch with a spare unit in case of trouble. Truck type switches also facilitate repairs, inspection, and provide a much safer installation than the usual type of open construction. Fig. 9 shows a typical inclosed truck type equipment. Where remote control is desired with push-button control at the motor, these switches may be made electrically operated. No further control is necessary when using squirrel-cage motors, with a separate feeder circuit for each motor.

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*A very comprehensive article describing this type of motor, written by R. A. Jones, appeared in the November, 1921, issue of the General Electric Review, and other articles in the September, 1921, and February, 1916, issues appeared on the same subject.

Slip-ring Motor Control

For the control of slip-ring motors driving condenser pumps or draft fans the primary panel may be similar to that used for a squirrel-cage motor (for full-voltage starting), except that an interlock should be provided between the secondary drum controller and the primary switch so that it is possible to close the primary switch only when the controller is in the starting position.

When automatic re-starting is wanted, the control can include a special block of secondary resistance with contactors controlled by under-voltage and current-limit relays so that in case of low-voltage these contactors will drop out, inserting the special resistance into the rotor circuit. On return of voltage the contactors will be reclosed by the current-limit relays, accelerating the motor to the same speed as before the interruption. This scheme is applicable to either hand or remote control.

Where motor-operated drum controllers are used in the secondary, these can be arranged to go back to the starting position in case of voltage failure. If the controller is normally operated from push-button control, it will bring the motor up to its lowest running speed on restoration of alternating-current voltage. If the motor is controlled from an automatic regulator, an under-voltage coil on the regulator will run the controller back to the starting position on low-voltage, and on return of voltage the motor will come up to the speed called for by the regulator.

Pressure Regulating Control for Slip-ring Motors Driving Boiler Feed Pumps

Control equipment has been developed for operating boiler feed pumps giving a combination of hand and automatic speed regulation which permits the selecting of three or four speed points by hand control and with automatic regulation by pressure regulator (13 points of pressure control) over a speed range slightly greater than each hand control step. Such an equipment consists of a master control panel and a contactor control panel. The former includes the primary oil circuit breaker, a double-diaphragm excess-pressure regulator operating a 13-point drum switch, a hand-operated master switch and the necessary instrument transformers and control switch. A contactor panel includes three accelerating and three regulating contactors together with the current-limit relays for control of the accelerating contactors. These relays also limit the current should the operator move the master switch faster than the motor can accelerate.

Assuming an equipment on which it is desired to have predetermined speeds: 60, 70, 80, 90, and 100 per cent, the master switch in its OFF position would permit the three hand regulating contactors to remain open, inserting sufficient resistance to reduce the motor speed to 70 per cent. The automatic regulating drum switch would then be operated over a range from 58 to 70 per cent speed.

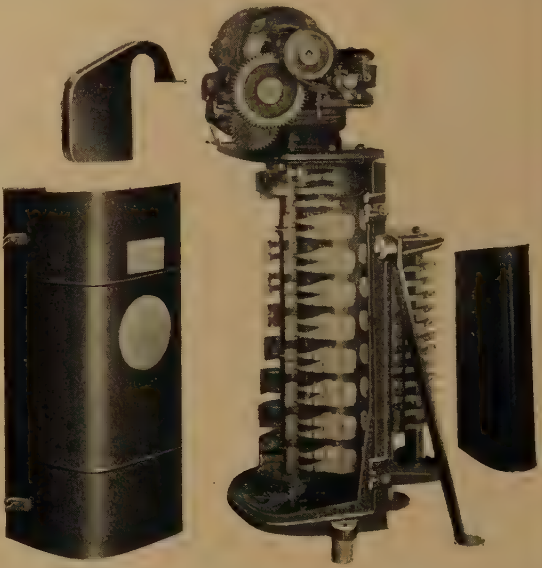

Fig. 10. 13-point Motor-operated Drum Controller and Drum Type Master Switch Geared Together

If the equipment was running too slow, the operator would move the master switch to the first point bringing the hand regulating speed from 70 up to 80 per cent. The automatic regulation would then be from approximately 68 to 80 per cent. If this speed were too low, the master switch would be moved to the third point or 90 per cent point; automatic regulation being operated from 78 to 90 per cent speed. If it is desired, an additional contactor could be added for short circuiting the automatic regulation, giving the maximum speed by hand control.

With such an equipment all that is necessary at starting is to close the control and oil circuit breaker. The automatic acceleration is provided independent of the pre-determined settings of the master switch or automatic regulated switch. This system provides extremely fine speed regulation for boiler feed pumps, and is being furnished for several of the large steam plants now being built.

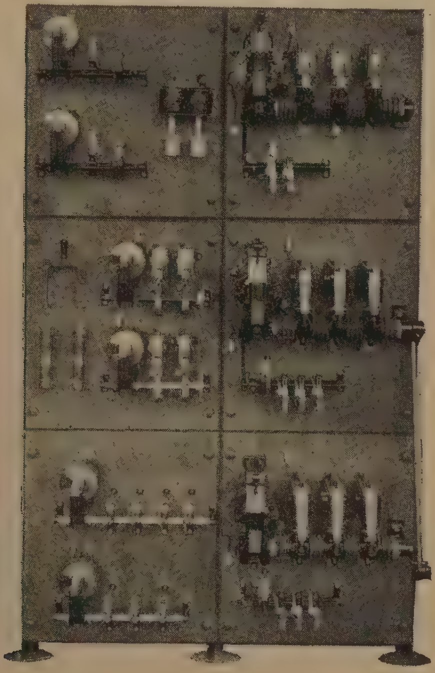

Fig. 11. Control Panel for Series Type Brush-shifting Motor Rated 150 Amp., 550 Volts

Control for Two Slip-ring Induction Motors Driving Fans

Automatic control has recently been applied to slip-ring induction motors driving induced draft fans. In this drive two motors are used, one of 100 h.p. capacity at 400 r.p.m. connected permanently to the fan and the other of 300 h.p. capacity at 600 r.p.m. connected to the fan through a magnetic clutch. The use of two motors in this manner provides better efficiency in operating the fan throughout its speed range, as the smaller motor will handle the load for the greater part of the time. The large motor is used only for emergency and heavy overload conditions.

The speed of each fan motor is controlled by a pilot-motor-driven drum controller which is notched along from point to point as called for by the pressure regulator controlling the system. Fig. 10 shows one of these controllers (13-point) with the auxiliary drum mounted on the back of the controller for handling the control circuits.

Group Control for a Bank of Boilers

Group control has been applied to these motors by employing a pressure regulator and pilot-motor follow-up master switch which operates all of the pilot motors simultaneously to increase or decrease all of the motor speeds. With this arrangement it is always possible to increase or decrease the speed of any one motor of the group, without affecting the speed of the other motors as individual control push-buttons are provided for each unit.

In this way re-adjustments may be easily made in case any of the motors gradually get out of synchronism with the other motors of the group. An electric tachometer on each fan is a material help in determining whether all motors are running at the correct speed.

Control for Series Type Brush Shifting Alternating-current Motors

In the application of the commutator type of alternating-current motor to boiler room auxiliaries, such as forced draft fans, it seems very desirable to provide for automatic control of the speed as the boiler pressure varies.

A system of control has been worked out to do this; involving magnetically operated line switches or contactors, a small reversible pilot motor connected through a suitable train of gears to the brush yoke of the main motor, a master switch of the drum controller type which is also driven by the pilot motor for maintaining a definite relation to the brush position, and a pressure regulator.

Such a control provides for having the motor brushes in a predetermined position before the motor can be connected to the line, this position being such as to assure sufficient torque for starting and yet keep the inrush current as low as practical. (On failure of voltage, the brushes will automatically come to this position.) After the motor is started the motor brushes will be shifted to whatever position the pressure regulator calls for.

In order to secure efficient operation over wide speed ranges on a motor having series characteristics, it is desirable to operate with its windings *Y*-connected over a part of the range and delta-connected over the remainder of the speed range. As the change is made from *Y* to delta or vice versa, a considerable change in motor speed results. In order to compensate for this the brushes are automatically shifted back to a new position giving approximately the same speed as was obtained before changing the connections of the motor windings.

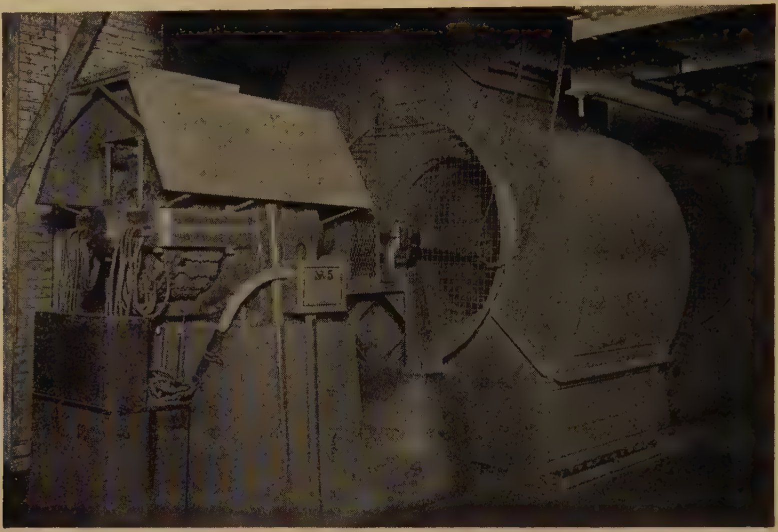

Fig. 12. 200-h.p. Series Type Brush-shifting Motors Driving Forced Draft Fans

When hand operation of the motor speed is desired a throw-over switch may be used to disconnect the circuits from the follow-up control and transfer it to a push-button station.

Group Control of Fans

Group control of two types has been applied to brush-shifting alternating-current motors. The first is similar to that described above for slip-ring motors, where a master switch controls the pilot motors for the group and no provision is made to insure that the individual motors will remain at exactly the same speeds.

Some hand adjustment may be necessary if the motors gradually work apart on automatic control. Fig. 11 shows a typical control panel used for this type of control.

The second method of group control provides a synchronous control for the brush-shifting mechanisms (which are operated by pilot motors) so that for any position of the regulator, the brushes on all the motors assume a corresponding position. This insures that all of the fans in the group will be operated at the same speeds except for slight variations due to individual motor characteristics. This system of control will give more accurate results than the first system of group control already described, and there will be no tendency for the different motors to work apart in speed. There is, however, a considerable amount of control equipment required to accomplish this synchronous control of brush-shifting motors, and a more simple type of control can be used for boiler-room fans where exact speed adjustment of groups is not essential.

Fig. 13. 4/6/8/12-pole, 12/8/6/4-h.p., 1800/1200/900/600-r.p.m., 220-volt, Squirrel-cage Motor Driving a 14-retort Riley Stoker

Fig. 12 shows a typical installation of a 200-h.p. series type brush-shifting motor driving a forced-draft fan.

Control of Stoker Motors

Where a flexible speed control is to be provided for stoker motors involving 3 : 1 or 4 : 1 speed range, the most desirable drive is probably a direct-current shunt motor with fully compensated windings, designed for wide speed range by field control. This requires a starting and speed regulating resistor and drum controller. The controller should be provided with a special dust-tight case so as to keep the contacts free from coal and ash dust.

Alternating-current Stoker Drive

There are, however, many cases where direct-current is not available for stoker drive and alternating-current motors must be used. There are about three choices in alternating-current motors for this service: (1) the shunt characteristic brush shifting motor described earlier in this article, (2) the pole changing squirrel-cage motor, and (3) the pole changing slip-ring motor.

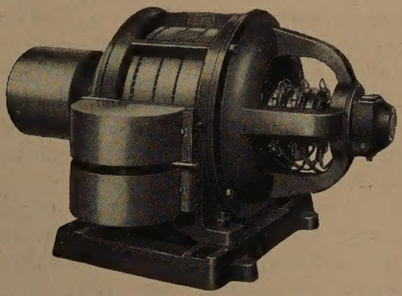

Fig. 14. 6/12-pole, 30/15-h.p., 1200/600-r.p.m., 440-volt Pole-changing Slip-ring Motor

Shunt Characteristic Brush Shifting Alternating-current Motor

Fig. 15 shows a typical motor of this type with pilot motor for remote speed control from a push-button station. This motor is furnished with a large drip cover (not shown) to protect the windings and commutator from all falling material. The control consists of a primary switch (usually of the magnetic type) and the alternating-current pilot motor shown in the photograph. Where hand control is satisfactory the motor as shown in Fig. 3 is suitable.

Pole Changing Squirrel-cage Motor

Fig. 13 shows a typical installation of this type of motor to a stoker. This includes a special type pole changing drum switch giving four definite speeds. A suitable primary switch is provided and may be interlocked with the drum controller so that when the handle is advanced from one position to another the primary switch is automatically opened, the pole connection changed, and the line switch reclosed. These motors can be supplied for either compensator starting or full-voltage starting. (The latter is preferable.) They are not supplied for voltages above 550.

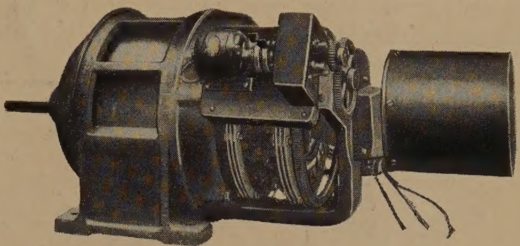

Fig. 15. 20/6.67-h.p., 1250/415-r.p.m., 440-volt Adjustable-speed Brush-shifting Motor with Pilot Motor Brush-shifting Mechanism

Pole Changing Slip-ring Motor

Fig. 14 shows an open type slip-ring motor having a 2 : 1 speed change by pole changing. An additional speed range of 2 : 1 is accomplished by secondary control, so that a total range of 4 : 1 is obtained. A switch is mounted on the motor frame for pole changing. Where the motor is not accessible, or where pole changing is a frequent occurrence, a drum switch can be substituted similar to the one shown in Fig. 13. For stoker service, either semi-enclosed construction or drip covers should be provided on the motor. A drum controller and resistor is provided for secondary control.

POWER SUPPLY

Where alternating-current power is used for supplying auxiliaries, this power may be obtained:

1. From the main bus.
2. From the house generator on a main unit.
3. From the house turbine generator set.
4. From some external supply.

Opinions vary as to the relative desirability of these sources of auxiliary power. Where heat balance enters into consideration, one system may clearly be superior to the others for any particular application. It is usually found that the best economy can be obtained in large stations by bleeding the main turbines for feed water heating, so that steam driven auxiliaries or house turbine generator sets are not necessary for this purpose. This leaves the way clear to the use of power from the main units or from house generators for driving the auxiliaries. The house generator has the advantage of electrical isolation from system disturbances. Fig. 16 shows the arrangement of such a unit.

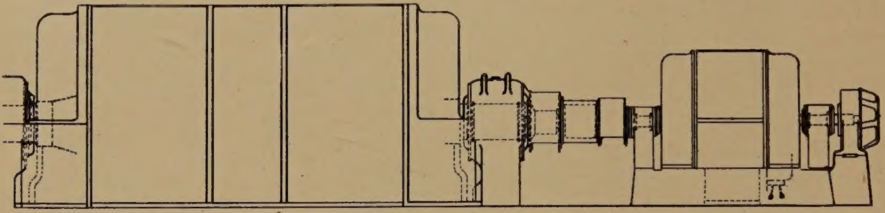

Fig. 16. Arrangement of Main and Auxiliary Generator and Exciter for Auxiliary Generator, Typical of Large Turbine Alternator Sets

Where auxiliary power is obtained from the main units for auxiliary drives, it seems very desirable to use unit power supply. Where each generator supplies its own auxiliaries, provision should be made for supplying the auxiliary bus for any unit from any other unit during starting or trouble periods. A small single-stage non-condensing turbine generator set seems desirable for starting up and for emergency power for auxiliaries.

The use of direct current allows the use of batteries as an emergency supply but has the disadvantage of lower economy and higher cost for most installations. Some operating companies have found it desirable to use duplex drives for some units where continuity of service is important. These may be arranged so that the unit normally drives from the motor with the turbine running idle and the turbine governor set to pick up the load on a decreasing speed of 5 to 7 per cent. Motor and turbine driven duplex units can also be used for obtaining proper heat balance where stage bleeding does not give sufficient steam for heating feed water at all loads on the station.

From the manufacturer's viewpoint, there would seem to be considerable advantage in using low voltage (220, 440 or 550 volts) for boiler room and coal handling equipment, rather than to use 2300-volt power. This gives a much higher factor of safety in the motor insulation than is possible at 2300 volts, and makes it possible to operate the stokers and other small motors from the same supply as used for the larger motors.

Control devices also have a higher factor of safety at low voltages and are in general considerably cheaper than 2300-volt equipment. On the other hand the heavier currents increase the ampere capacity of switches and may involve a greater expense in wiring and cables.

While there is a great variety of electrical equipment used for driving auxiliaries, and little or no standardizing has been done along this line, still there are certain distinct tendencies noticeable in the more recently designed steam stations. Among these are the use of auxiliary generators driven from main units, truck type switching equipment for auxiliaries, full-voltage starting of squirrel-cage motors, and the application of alternating-current motors to stoker drive.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Armature Windings

Contribution to the Theory of Direct-Current Armature Winding. Heather, H. J. S.
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Waste-Packed Bearing Design and Operation. Bethel, C.
Elec. Jour., Mar., 1924; v. 21, pp. 115-118.

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Three-Car Articulated Train for Detroit. Colby, A. C.
Elec. Rwy. Jour., Mar. 8, 1924; v. 63, pp. 357-362.
(Illustrated description of a three-car train for trolley service.)

Converters, Synchronous

Flash Guards for 60-Cycle Railway Converters. Newton, R. H.
Elec. Jour., Mar., 1924; v. 21, pp. 105-106.

Electric Controllers

Operation and Care of Drum-Type Manual Controllers for Motors. James, H. D.
Power, Mar. 4, 1924; v. 59, pp. 368-369.

Electric Drive—Machine Tools

Wood and Metal-Working Machinery Motor Requirements. Jorstad, H. C.
Elec. Wld., Mar. 15, 1924; v. 83, pp. 519-521.

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Lewis Mine Provides Against Electrical Shutdown and Uses Block System of Development. Brosky, Alphonse F.
Coal Age, Mar. 6, 1924; v. 25, pp. 343-346.
(Description of a-c. equipment used by the Lewis Mine of the Hudson Coal Company, Wolf Summit, W. Va.)

Electric Locomotives—Testing

Otheographic Records of Wheel Effects on Rails.
Engng. News-Rec., Mar. 13, 1924; v. 92, pp. 441-442.
(Illustrated description of the construction and use of the otheograph, a device for recording vertical and lateral forces produced by locomotive wheels.)

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Characteristics of a D-C. Series Machine Self-Excited by Rectified Current for Purposes of Regenerative Control. Archibald, R.D.
I. E. E. Jour., Mar., 1924; v. 62, pp. 233-242.
(On the theory and possibilities of a special regenerative type of trolley-car motor.)

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Some High Points on Modern Transformers. Palme, Arthur.
Power, Mar. 11, 1924; v. 59, pp. 402-403.
(Brief, illustrated article describing the salient features of some recently built large-capacity transformers.)

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High-Tension Transmission Lines. Pannell, Ernest V.
Engr., Mar. 14, 1924; v. 137, pp. 272-273.
(Serial article taking up the essential features of conductors, insulators, and supports.)

Transmission at 220,000 Volts. Barre, H. A.
Elec. Wld., Mar. 15, 1924; v. 83, pp. 515-518.
(Descriptive account of the Southern California Edison Company's 220-kv. Big Creek lines.)

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Recent Progress and Future Development in Electric Welding. Smythies, R. E.
Bul. of Hyd. Pr. Comm. of Ont., Feb., 1924; v. 11, pp. 35-44.

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Measurement of Electrical Energy in A-C. Circuits. Stubbings, G. W.
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Steel Works Lighting. Blakeslee, D. W.
Iron & St. Engr., Mar., 1924; v. 1, pp. 111-115.

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Potential Transformer Fuse Tests. Hess, P. M.
Elec. Wld., Mar. 8, 1924; v. 83, pp. 467-471.
(Results of tests on safety and reliability of 13,200-volt cartridge and expulsion fuses.)

Hydraulic Transmission

New Variable Speed Gear.
Engr., Mar. 7, 1924; v. 137, p. 262.
(Illustrated description of the Schneider hydraulic transmission gear.)

Hydroelectric Development

Big Power Plants in Northern Ontario.
Elec. News, Mar. 15, 1924; v. 33, pp. 76-79.
(Description of several Canadian hydroelectric plants, with map showing plants, lines, etc., in Northern Ontario.)

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Elec. News, Mar. 15, 1924; v. 33, pp. 65-72.
(Illustrated description of the Queenston development of the Hydro-Electric Power Commission of Ontario.)

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Wld. Power, Mar., 1924; v. 1, pp. 149-157.
(On the manufacture, properties and uses of insulating varnishes. Serial.)

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Thunderstorm Researches Versus No Lightning Arresters. Creighton, E. E. F.
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(Comments on article by Dr. Norinder in *Electrical World*, Feb. 2, 1924, pp. 223-226, which latter was an abstract translation of the original Swedish in *Teknisk Tidskrift*, Oct. 6, 1923.)

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Experiences with Multiple Feed, High Pressure Lubrication. Humpton, Louis R.
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Power, Mar. 11, 1924; v. 59, pp. 404-405.
(Partial list of inspection instructions issued by the Federal Light & Traction Co., New York.)

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Ventilation and Noise Control of Sub-Station Machinery. Hague, F. T.
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(Paper read before the Radio Society of Great Britain.)

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Elec. Wld., Mar. 8, 1924; v. 83, pp. 472-474.
(Discusses the choice of equipment for power-factor correction.)

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Elec. Rev., Mar. 7, 1924; v. 94, pp. 395-396.
(Abstract of paper read before the I. E. E. Serial.)

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Discussion on "Loud-Speakers for Wireless and Other Purposes."
I. E. E. Jour., Mar., 1924; v. 62, pp. 265-298.
(A symposium consisting of articles by nine different authors. With the resulting discussion forms an extensive paper.)

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Some Experiments on the Screening of Radio Receiving Apparatus. Barfield, R. H.
I. E. E. Jour., Mar., 1924; v. 62, pp. 249-264.
(Presents the results of tests on different kinds of screens.)

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I. E. E. Jour., Mar., 1924; v. 62, pp. 213-231.
(A description by the Chief Engineer of the line.)

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Air Core Concrete Type Reactors.
Met.-Vick. Gaz., Jan., 1924; v. 8, pp. 12-13.
(Brief, illustrated description of a Metropolitan-Vickers apparatus.)

Steam Engines—Testing

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Power Pl. Engng., Mar. 15, 1924; v. 28, pp. 323-325.

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Voltage Regulation on A-C. Distribution Systems. Schwenger, C. E.
Bul. of Hyd. Pr. Comm. of Ont., Feb., 1924; v. 11, pp. 45-58.

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